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Summer River Water Temperature Changes in the Musconetcong River and Their Potential Impact on Aquatic Habitat

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ABSTRACT

Water temperature changes in rivers can happen quickly for multiple reasons, and can drastically impact the river in many ways. The potential for temperature shifts to impact rivers is especially important in the summer, for aquatic habitats, as the warm temperatures can stress populations. This is especially true for trout populations, a temperature-sensitive fish. Since temperature is the most important factor in the growth of trout, these temperature changes can be life threatening. Therefore it is important to monitor temperatures in the Musconetcong River, classified as trout maintenance waters (Musconetcong Advisory Committee et al., 2003), because of the potential negative impact on trout. The summer water temperatures in the upper Musconetcong River, New Jersey, were assessed during 2011, 2012, and 2013, to see how suitable the water temperatures are for trout. Sensors in the river recorded the water temperature every 15 minutes at three to four spots. Water temperature and river discharge data was compared from the same time period using the USGS gage immediately upstream of the field sites. An important initial finding is that the air temperature has a positive correlation with the water temperature while discharge has a negative correlation with the water temperature. During low discharge conditions air temperature has a greater influence on water temperature than when discharge is high.

MONTCLAIR STATE UNIVERSITY

/ Summer River Water Temperature Changes in the Musconetcong River and Their Potential Impact on Aquatic Habitat /

by

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1. INTRODUCTION AND BACKGROUND

Water temperature changes in rivers can happen quickly for multiple reasons, and can drastically impact the river. The summer is when most of the variations in water temperature occur because of changes in the depth of the water, solar radiation, cloud cover, and low flows (Caissie et al., 2001). Diurnal air temperature changes, precipitation events, and discharges into the river system from impoundments behind dams, power generators, or effluent can all influence the temperature in a river. The potential for temperature changes to impact river aquatic habitat is especially important in the summer, as the warm temperatures can stress populations and reduce available habitat quality and quantity.

Temperature changes are especially important for thermally sensitive species such as trout. Temperature is generally assumed to be the most important factor in the growth and development of trout, and large temperature changes can be life threatening (Hari et al., 2006). The trout ova are able to develop without a high mortality between water temperatures of 3°C and 15°C (Hari et al., 2006). Trout have been found to have a maximum growth rate between water temperatures of 13.1-13.9 degrees Celsius with growth stopping below approximately 2.9 and 3.6 degrees Celsius and above 18.7 and 19.5 degrees Celsius. During the summer there are reports of trout finding pools for survival with the preferred maximum temperature of 25 degrees Celsius, which is the incipient lethal temperature, with survival being about seven days (Hari et al., 2006).

Dissolved oxygen also plays a large role in trout growth and development, and can be viewed as a function of the water temperature, where the cooler temperatures have more dissolved oxygen, and the warmer have less dissolved oxygen. With the increase in water temperature at critical times of the year, the water quality is adversely affected and decline in trout populations could be a result due in part to the low levels of dissolved oxygen (Morrill et al., 2005). The decrease in dissolved oxygen levels affects the entire aquatic ecosystem, and the rate of the water temperature increase can also adversely change the metabolic rates of fish, or possibly even becoming lethal (Gooseff et al., 2005). As water temperature increases there is a decrease in the solubility of gases, producing a corresponding decrease in important dissolved gases such as oxygen (Molony, 2001).

Dissolved oxygen is not the only determining factor in trout survival. Other studies have found that trout are more susceptible to adverse effects from higher water temperatures than from low dissolved oxygen levels (Elliot, 2000; Matthews et al., 1994). Both Elliot (2000) and Matthews et al. (1994) found that trout will stay in the deepest part of small pools in the river which has the lowest water temperature, but not the most dissolved oxygen levels. A study by Krider et al. (2013) on streams in Minnesota used linear regression models to determine the relationship between air and water temperature as well as the influence of groundwater recharge on water temperature. Like this study, Krider et al. (2013) examined how the groundwater discharge affected the water temperature and air temperature relationship. When streams have large amounts of groundwater input then the stream's response to air temperature is less controlled than the streams with little to no groundwater input. An earlier Mohseni and Stefan (1999) study also found a positive correlation when comparing water and air temperatures. When the water temperatures increase in the summertime, the dissolved oxygen levels decrease and possibily reach critically low levels (Morrill et al., 2005). One way to combat these inevitable summertime water temperature increases is to create small lower water temperature pools for trout to live in during times of high water temperature. The creation of these pools can be done in a few different ways; an influx of cool water from cool groundwater, tributary streams or surface springs and the thermal stratification of the pools can help as well (Tate et al., 2006). The stratification of the pools may be possible in the Musconetcong River without the use of a barriers such as large woody debris or a gravel bar to slow down parts of the river and allow it to stratify (Matthews et al., 1994), because it is generally a fast and shallow river.

In addition to forming pools by slowing down the river, large woody debris are needed in rivers to perform other key functions, including the stabilization of bedforms and channel banks, and providing shade and cover for aqautic organisms (Booth et al., 1997). Large woddy debris are also found to retain nutrients in headwater areas and create aquatic and riparian habitat (Curran and Wohl, 2003). The pools created by and adjacent to the large woody debris are sought out by trout as refuge from possible predators, high flows and high water temperatures (Booth et al., 1997). The presence and location of large woody debris is the determinant of the formation of pools with pool frequencies found to be two to three times greater than in large woody debris-free rivers (Booth et al., 1997). Both Booth et al. (1997) and Curran and Wohl (2003) found that an increase in the amount of large woody debris would have a strong positive effect on the flow resistance of the river. Therefore large woody derbis would slow down the river, giving it a chance to cool down and the cooled water would sink into one of the pools.

Upstream river discharge and air temperature are two critical variables that determine river water temperature. Groundwater is also known to have an influence on the water temperature in the Musconetcong River, although it is not measured in this study. This study focused on the water temperature changes and discharge amounts of the upper Musconetcong River during the summers of 2011, 2012 and 2013, at three to four different points along the river. High water temperatures can directly affect trout mortality. These locations were chosen near the origin of the Musconetcong River, where it flows out of Lake Hopatcong. The first focus of this study was to assess a concern with the high water temperatures in the Musconetcong River, which make the water unsuitable for rainbow and brown trout. This study will also research the hypothesis that at lower discharge rates the air temperature has a stronger influence on the water temperature changes than at higher discharge rates, which is when discharge has a strong negative influence on water temperature.

Located in northwest New Jersey (Figure 1), the Musconetcong River originates from Lake Hopatcong. The Musconetcong River was classified by the New Jersey Department of Environmental Protection (NJDEP) as Trout Maintenance Waters, which means that the river must support trout throughout the year (Musconetcong Advisory Committee et al., 2003). In 2006 federal bill S1096, the "Musconetcong Wild and Scenic Rivers Act", designated portions of the river as a component of the National Wild and Scenic River System (National Wild and Scenic Rivers System). The National Wild and Scenic River System was created in 1968 and is meant to preserve certain rivers with outstanding cultural, natural and recreational values (National Wild and Scenic Rivers System). It keeps the special character of the rivers intact while recognizing the potential for the use and development of the rivers (National Wild and Scenic Rivers System). There are four other rivers in New Jersey besides the Musconetcong River that are designated as wild and scenic (National Wild and Scenic Rivers System), and there are approximately 6,450 miles of river in New Jersey and of that more than four percent of the river miles or 262.9 miles are designated as wild and scenic (National Wild and Scenic Rivers System).

Lake Hopatcong was first discovered about 12,000 years ago by a Native American community, Lenape, and is the result of the retreat of the Wisconsin glacier. The first known human interaction with the Musconetcong River was also about 12,000 years ago when the Lenape lived in a sub-arctic climate, hunting caribou and elk among other mammals that are no longer in this region (Lake Hopatcong Commission, 2013). Over the next several thousand years the climate in the area became warmer and the boreal forests turned into the deciduous forests of today. Glacially-formed lakes, the largest being Lake Hopatcong, fed into the Musconetcong River and the river then attained its current size. During the 18th Century, the Lenape Indian population was on the decline and saw their several thousand year old occupation come to an end just as European settlers came to the river. Beginning with European settlement and continuing through today the river has undergone massive alterations, especially compared to the minimal impact over several thousand years of the Native Americans. Eventually people started putting up summer cottages around the river and lake, and these eventually turned into permanent residences (Brunner; Lake Hopatcong Commission, 2013).

Precipitation and the Hopatcong State Park personnel control the water levels of Lake Hopatcong. The Hopatcong State Park personnel manage the lake level with the goal of protecting the natural and scenic rescources and the environmental health of Lake Hopatcong and the Musconetcong River System, minimize protential damage to property and waterfront structures, and maximizing recreational opportunities. This must all be done while maintaining the minimum flow requirements to protect the downstream uses which include: aquatic biota, water quality, and historic resources. In order to accomplish this, Lake Hopatcong is required to meet the minimum passing flow of 12 cubic feet per second (cfs). When the water spilling over the dam is enough to meet the 12 cfs requirement, the passing flow gates would close (New Jersey Department of Environmental Protection, 2011).

2. METHODS

To measure the 2013 river temperatures, Dr. Galster and I went into the river with Leveloggers (Solist Inc.) and curved iron rods to hold them into place. The Levelogger is a small cylindrical device that records the temperature and pressure of the surrounding environment. The time interval was set for every 15 minutes for all three summers of 2011, 2012, and 2013. The curved iron rods were hammered into the bed of the river and the Leveloggers were secured to the rods so they were resting on the bed of the river. After the Leveloggers were in place, we measured distances from their location to local landmarks, usually rods on the banks of the river, in order to find them later. At the end of the summer we took them out of the river and downloaded their data to MS Excel. A separate Levelogger was installed in the state park office at Lake Hopatcong to record atmospheric pressure. This Levelogger allowed for the water depths to be calculated by subtracting the atmospheric pressure of the sensor in the office from the total pressure (water plus atmospheric) of the sensors in the river. I then compared the water temperature data to the discharge data from the same time period using the USGS data. The air temperature, obtained through Rutgers University, was another important aspect to compare against the water temperature (Rutgers University, 2013).

The USGS gage used in this study is the Musconetcong River at outlet of Lake Hopatcong NJ, gage number 01455500, and is managed by the New Jersey Water Science Center. The gage is in Roxbury Township, Morris County on the left bank, 91.4 meters downstream of the Lake Hopatcong Dam and upstream of the Country Route 607 Bridge (United States Geological Survey, 2014).

In 2011 the sensors recorded the water temperatures of the river every 15 minutes for the entire summer, June to August, in three different spots. These spots were upstream, near the mouth of the Lake Hopatcong, further downstream of the last one, but still upstream of Lake Musconetcong, and the last one was downstream of Lake Musconetcong (Figure 1). These spots will be referred to as the Outlet, Willow St, and Downstream sites respectively. During the summer of 2012 the sensors were placed in the same spot as 2011 in the Outlet site but about 20 meters downstream, at the Willow St. site, from the 2011 spot. In 2012, the Downstream site was moved about 1500 meters upstream from the 2011 spot to behind the Musconetcong Sewerage Authority building in a locked fenced in area. Also in 2012, the Drain Way site was added approximately 500 meters downstream from the Downstream site. In 2013, the Outlet and Willow St. sites were in the same location as 2012 while the Downstream site was moved approximately 1000 meters downstream from the 2012location. This was moved from behind the Musconetcong Sewerage Authority in 2012 because it became too much of an inconvenience to get to the site behind the locked fence, and none of the sensors appeared to be tampered with, so the locked fence was unnecessary. The Downstream sites may not be comparable year to year because of their changes in location hydrologically; from 2011 to 2012 there is a pond between the two sites and the river splits after it before reaching the 2012 site, and from 2012 to 2013 there is a tributary adding water to the river. Another site was also added in 2013, known as the Tributary site, which was between the Outlet and Willow St. sites and different than the 2012 Drain Way site.

3. RESULTS

During the summer of 2011 there was a correlation between the air and water temperature for all three of the sites. Figure 2 compares the daily maximum observed air temperatures and the daily maximum observed water temperatures in all three of the sites measured from mid June to late August. The peak water and air temperature was observed on July 22nd (Figure 2) as the large point in the middle of the graph. Monthly graphs were made for 2011 illustrating the air and water temperatures fluctuations; Figure 3 shows an example of this with the July temperatures. Figure 3 shows the fluctuations and the large temperature peak on July 22nd which is the warmest air temperature day of the year with 36.1 degrees C and the day of the warmest water temperature reading for the year for both the Willow St. (30 degrees C) and Downstream sites (30.9 degrees C).

The summer of 2012 also saw a correlation between air temperature and water temperature for all four sites measured. Figure 4 shows the daily maximum air temperature and daily maximum water temperature for all four sites over the summer, mid June to late August. The largest peak in air temperature for the summer is on the 18th of July, which is also when some of the sites reached their summer peak or at least rise. Then after that on the 19th and 20th of July as well as before it on the 26th and 18th of June, the air temperatures fall and this is mimicked by the water temperatures for all of the sites. The monthly graph for August can be seen in Figure 5, which has many fluctuations in air temperature that are seen in the same pattern in each of the sites' water temperature readings. The fluctuations in water temperature occur within a few hours after the air temperature changes. Air temperatures are warmest in the afternoon and the water temperatures are highest in the late afternoon or early evening (Matthews et al., 1994).

There was also a correlation between air and water temperature of all sites during the summer of 2013. Figure 6 shows this by plotting the maximum daily air temperature and maximum daily water temperature of all four sites against time, from mid June to late August. The peak air temperature is on the 18^{th} and 19^{th} of July having the same maximum air temperature on both days, this is also a peak in the site's water temperatures. There are also air temperature lows on the 1^{st} and 24^{th} of July and 18^{th} of August which also have a water temperature decrease on those days for all sites.

Each year had times when the water temperature was above the 25 degree C threshold. Figure 7 shows the Willow St. site, with the peak once again in late July, and a majority of measurements taken were above 25 degrees, the other two sites have very similar graphs. Since the 25 degree C threshold is critical for trout survival it is important to consider when the sites were above and below 25 degrees C. The temperature readings above 25 degrees C for the most upstream site, the Outlet site, for 2011 was 59.9 percent of the summer. Approximately 1000 meters downstream in the Willow St. site the temperature above 25 degrees was 32.8 percent of the summer. The Downstream site, in 2011, was more similar to the Outlet site with a 57.0 percent of the readings being greater than 25 degrees. During the summer of 2012, the temperarture readings above 25 degrees were during 65.5 percent of the time for the Outlet site while the Willow St. site was much less with 32.1 percent of the summer being above 25 degrees. The Downstream site had the coolest readings of all four sites that year with 0 percent of the readings being above 25 degrees. The Drain Way site sensor was placed into the river later than the other three, on the 18th of July, and only had temperature readings higher than 25 degrees in the first few days. 0.7% of the time the Drain Way site had a temperature reading of above 25 degrees.

Figure 4 shows the comparison between the daily maximum observed air temperatures and the daily maximum observed water temperatures in all four of the sites measured from mid-June to the end of August 2012. Figure 4 illustrates that there is a positive correlation between the air and water temperatures in each of the sites were in general the water temperature will rise and fall as the air temperature does. The August water and air temperatures fluctuate in the same way as each other throughout the month (Figure 5), which illustrates the correlation between the two. The Downstream site is the only one in 2012 which is always below 25°C, with the highest temperature only being 24.2°C, while the other two sites show that by mid- to late June there are multiple measurements above 25 degrees. The Drain Way site only has a few points above 25 degrees and only reaches to 25.2 degrees in the beginning of the measurements then lowers to below 25 degrees and remains lower which can be seen in Figure 8.

During the summer of 2013, the Outlet site had temperature readings of above 25 degrees at 35.3 percent and the Willow St. readings at 26.8 percent above 25 degrees. During 18.8 percent of the summer, the Downstream site was above 25 degrees and the Tributary site was under 25 degrees for the entire summer of 2013, reaching as high as 24.6 degrees for only 1.25 hours for the whole summer.

The air temperature affects the water temperature more during periods of lower discharge than when there is higher discharge (Figure 9 & 10). There are also negative trends seen between the maximum daily discharge versus maximum daily water temperature graphs for each site and year. The 2013 Tributary site water temperatures did not correlate with any recorded discharge values because it was the only site measured that was not part of the Musconetcong River, but the air temperature still affects the water temperature. During 2013 and 2012 the further downstream the measurements were the cooler the water was for the summers. In contrast in 2011 the Downstream site had the highest water temperatures and the Willow St. site had the lowest water temperatures. All of the sites, except for the Downstream and Drain Way sites in 2012, and the Tributary site in 2013, were above 25 degrees water temperature for at least 18 percent of the time.

4. DISCUSSION

The increasing summertime air and water temperature are especially important for thermally sensitive species such as trout. Temperature is generally assumed to be the most important factor in the growth and development of trout, and large temperature changes can be life threatening (Hari et al., 2006). During the summer, trout have been found to have a preferred maximum temperature of 25 degrees C, which is the incipient lethal temperature with survival being about seven days (Hari et al., 2006). With the increase in water temperature at critical times of the year, the water quality is adversely affected and decline in populations could be a result due in part to the low levels of dissolved oxygen (Morrill et al., 2005). Since there is a direct positive correlation between air and water temperatures, high air temperatures could be disastrous for trout. The highest water temperature for the summer of 2011 was 30.9 degrees C and was recorded on July 22nd. The highest water temperature for 2012 was 30.2 degrees C recorded on July 18th and 2013 was 31 degrees C, and was also recorded on July 18th. All of these days were also relatively high air temperature days which illustrates the correlation between air and water temperature. These are also low discharge days depicting that when the discharge is low the air temperature has a larger effect on the water temperature than discharge. Figure 11 shows that at lower daily maximum discharge rates, there is an overall trend of the water temperatures increasing with increasing discharge rates. This is because the air temperature controls the water temperature more at low discharges, which is shown in Figure 12. Figure 12 shows the maximum daily air temperature vs. the daily maximum water temperatures on low discharge days for all three years with 2013 having the steepest slope and lowest intercept which means it is more affected by air temperature than any other year (Kirder et al., 2013).

4.1. TEMPERATURE PEAKS IN JULY

The highest water temperature for all three summers, and in all of the sites, was recorded in the month of July. The air temperatures during 2011, 2012, and 2013 were in the top six warmest Julys across New Jersey since 1895 (Robinson, 2013). July 2011 was the second warmest across New Jersey at an average of 26°C and was only 0.1°C away from the number one spot which was 1955 with 26.1°C (Robinson, 2013). July 2012 was the sixth warmest July in New Jersey, at 25.6°C, and 2013 was fifth at 25.7°C (Robinson, 2013). The 22nd of July, 2011 was one of the ten hottest New Jersey days since 1895 and during the month each of the 21 counties equaled or exceeded the 37.8°C mark (Robinson, 2011).

These warm air temperatures significantly affected the water temperatures during these hot times, especially at periods of low discharge. July 22, 2011 also saw the maximum water temperature for the Willow St. and Downstream sites while the Outlet site had its maximum temperature two days later on July 24. In 2012, the January-July interval was the warmest it has ever been in New Jersey since 1895 with 13.2 °C (Robinson, 2012). Of the 54 stations measuring air temperature around New Jersey by Rutgers University, at least one of them reached a 32.2 °C maximum for 22 days during July 2012 (Robinson, 2012). 2013 July air temperatures are best characterized by the warm nighttime temperatures which did not drop below 21.1°C for 26 days at one or more of the over 50 New Jersey Weather and Climate Network stations (Robinson, 2013). At night when the water temperatures can drop besides precipitation events so if the air temperature remands warm at night then the water temperature does not have a chance to cool.

For 2012 and 2013, the warmest site is the Outlet site, the most upstream site and the coolest is the most downstream site. 2011 was different because the Downstream site was the warmest for the beginning of the summer, until July 12th, and then again at the peak for the summer on the 22nd of July, but after that the Outlet site was the warmest and the Willow St. was the coolest for much of the summer. The Outlet site sensor was placed just downstream of the Lake Hopatcong outlet because there needed to be a site near where discharge is measured and where water is coming from Lake Hopatcong. This was in order to record the temperature of the Lake Hopatcong discharges, and observe the effect of the discharge on the water temperature. The location could not be too close to the outlet because there is more traffic there, so it was placed downstream of the gage station. The Outlet site had the highest water temperatures for 2012, 2013, and some of 2011 because the discharge from Lake Hopatcong could be warmer water spilling over the dam. In order to meet the discharge requirements, the Lake Hopatcong management allows the water to spill over the top of the dam instead of opening the gates at the bottom. The discharge over the top of the dam is not shaded, and if the lake is thermally stratified it would come from the warmer epilimnion. This water is warmer than the downstream water that has been shaded after flowing in the river or the groundwater recharge or tributary water the river receives. The Willow St. site location was chosen because it was downstream of the tributary, which was later measured in 2013, and upstream of Lake Musconetcong (Figure 1), so the effect of the tributary can be determined. The Willow St. site is also shaded, cooling the water, and has the input of the tributary water which was measured in 2013 and was cooler. The Downstream site was located downstream of Lake Musconetcong to measure the effect of the lake and the effects before the river has a large tributary enter it (Figure 1). The Downstream site is the coolest site during 2012 and 2013 and during part of 2011. It is also shaded and further downstream from Lake Musconetcong than the Willow St. site is from Lake Hopatcong. This means that the Downstream site has a longer time in the shade to cool down as well as mix with the cooler groundwater recharge and tributary water. The summer of 2011 is the only one where throughout the summer the Downstream site had the highest water temperatures, with the Outlet site having cooler temperatures and the Willow St. site having the lowest water temperatures (Figure 13).

Figure 13 also illustrates the effect that discharge has on the water temperatures of all the sites. 2011 is different from the other two years because it has two discharge peaks, one at the end of June and the other in mid-August, instead of only one in the beginning of the summer. During both of the discharge peaks the water temperatures fall and while discharge is low (< 50 cfs), the water temperature reaches its maximum for the summer. Figure 14 shows the first discharge peak from June 14^{th} to July 4^{th} 2011 and the Outlet site water temperatures. The initial, smaller, discharge increase occurs on the 17^{th} which is also when the water temperature decreases unitl the next day when discharge falls and water temperature increases until the 23^{rd}. At this point the discharge startes to increase to its maximum for the summer, causing the water temperature to fall again. This is followed by low discharge and higher water temperatures before another smaller increase in dischagre and a slight drop in water temperature. These peaks are also shown in Figures 15, 16, and 17 where the effect of discharge on water temperature can be seen even closer and the lag time is shown as well. The lag time for each of the peaks is within the hour of when discharge starts to increase, water temperature decreases. This rapid response is because of the close proximity of the Lake Hopatcong Dam to the Outlet site.When there is larger amount of dischagre it is because of the additon of water from the flood gates on the dam (Figure 18), which is also drawn from the top of the lake. When the discharge spills over the top of the dam it is warmer water because it is on the top of the lake. The increased discharge could come from a precipitationevent spilling over the top of the dam, which is generally cooler than the air termperature during the summer.

4.2. DISCHARGE EFFECTS ON WATER TEMPERATURE

Like 2013, the 2012 discharge pattern has higher discharge in the beginning of the summer until late June. However unlike 2011 and 2013, the maximum discharge only reaches 50 cfs, as opposed to the 300 cfs in the other two years. Most of the discharge occurred early in the summer of 2012, which is why the water temperatures were near the lowest for the summer (Figure 19). Over the course of the summer of 2012, the water temperatures tended to be warmer the more upstream the site was. Early in the summer high discharge has an effect on the Outlet site water temperature because it is closest to where the discharge measurements are taken. Figure 20 shows how the Outlet site was affected by discharge by only showing the measurements taken from mid- to late June when the discharge rate is falling and the water temperature is rising. The discharge starts at its maximum for the summer of 2012, and decreases to near the low for the summer. While the discharge is higher in earlier part of the summer the water temperature is lower and then as discharge begins to fall, water temperature rises. There is a small increase in discharge in the middle of the graph which is also when there is a slight decrease in water temperature.

In 2013 all the sites along the Musconetcong River show that at lower discharge rates the air temperature has a stronger influence on water temperature than at higher discharge rates. Figure 21 shows the correlation between the maximum observed air temperatures and maximum discharge rates for each day during July 2013. The air temperature has a positive correlation with the water temperature, especially when the discharge decreases below about 20 cfs; as the air temperature increases so does the water temperature (Figure 9). With discharge lower, to less than 20 cfs, the amount of cooler water the river is receiving is low and this gives the air temperature and solar radiation time to influence the water temperature.

The discharge has a negative correlation with water temperature at high discharge where increasing discharge lowers the water temperature (Figure 10). Early in July 2013, there were high discharge rates and low water temperatures, especially when compared to the higher air temperature. Figure 22 shows the 2013 15 minute increment data set from mid- to late June for the discharge rates and the water temperature. This figure illustrates the strong influence that discharge has on the water temperature, and overall the trend is that as the discharge rates decrease the water temperature increases. Even the small increases of water temperature can be lined up with small decreases in the discharge rates, and valleys in the water temperature line up with the peaks in discharge rates seen in Figure 22. Figure 23 contains all the data set for each of the 2013 sites along the river, as well as the discharge rate coming from Lake Hopatcong, and shows trends of the temperature differences between each site and the influence discharge has on the water temperature. Discharge rates do not play a large role in affecting water temperature for this summer because it trails off after about July 12th but before that it is clear the affect they have on three of the four sites.

Discharge of the main stem of the Musconetcong does not affect the Tributary site water temperatures. Therefore the Tributary temperature does not correlate with the discharge rates, unlike the other three sites. Like the other three sites, the Tributary site water temperature is well-correlated with the air temperature. The Tributary site is probably fed by groundwater recharge, although this was not measured in this study. The tributary does affect the temperature as its discharge affects the main river water temperature. The groundwater recharge must not be too high though, as the Tributary site's temperature correlates well with the air temperature.

After the discharge rates level off in 2013 another pattern emerges: the further the sites get from Lake Hopatcong, the cooler the water temperature. The farthest upstream site, the Outlet, had a higher overall temperature when compared to the second site, Willow St. Meanwhile the third site (Downstream) also had a higher overall temperature when compared to the second site.

Figure 24 shows the maximum daily discharge vs. the maximum daily water temperatures for the Outlet, Willow St., and Downstream sites. The Downstream site had the steepest slope and the lowest intercept of all three of the sites suggesting that it is the most meteorologically controlled (Krider et al., 2013). The Outlet site had a similar slope and intercept to the Willow St. site but had the shallowest slope and the highest intercept.

This means that the Outlet site is least controlled by weather (Krider et al., 2013) which would make sense because it is closest to the outlet of Lake Hopatcong so the discharge would effect it more than anyone site. The Willow St. site is downstream of the Outlet site so it would still be affected by the discharge but not as much as the Outlet site. The Downstream site is furthest from the discharge location, therefore it would be least affected by the discharge and more affected by the weather and air temperature.

4.3. AIR TEMPERATURE EFFECTS ON WATER TEMPERATURE

Since trout have a maximum of 25 degrees Celsius water temperature for a week in which they can survive (Hari et al., 2006) then determining how often and where the river is above or below that 25 degree mark is critical. Once the temperatures rise above the incipient lethal temperature, trout have been known to use small pools as refugia from the high water temperatures and low dissolved oxygen levels (Elliot, 2000). Table 1 shows the percentage of each summer for each site where that site had a temperature reading that was above 25 degrees. During 2011, the Outlet site and the Downstream site both had temperatures above 25° C more than half the time. The Willow St. site had 33 percent of temperatures exceeding the critical level, and the site is between the other two far warmer sites.

The next summer, 2012, the Outlet site had a five percent difference from 2011, while the Willow St. site stayed about the same (Table 1). The Outlet sites' five percent more difference could be due to the way the dam is built to draw warm surface water from the lake, increasing the Outlet site temperature slightly. The Willow St. site percentage was approximately the same as in 2011 because it is in the same area and it is shaded so the temperature would be cooler than the Outlet site. There was a huge improvement from 2011 to 2012 in the Downstream site, going from almost 60 percent down to less than one percen;t making it an ideal location as almost the entire summer it was below 25 degrees C. The Downstream site was moved further downstream from 2011 to 2012, making it dificult to make direct comparisons from year to year. 2013 had the lowest percentages for the Outlet and Willow St. sites with just over 35 percent and under 27 percent respectively. The Downstream site was again moved further downstream from 2012 to 2013, and a large tributary is feed into the river between the two sites; 2013 was under 19 perecent.

On July 18th 2012 another site was added, the Drain Way site, and only had a a few readings above 25 degrees, with a total of 0.7 % of the summer being above 25 degrees. In 2013 a new site was added on July 16th at a tributary, letter "E" in Figure 1; which enters the Musconetcong River between the Outlet and Willow St. sites. This site is very shallow and is shaded for much of the summer with the lowest temperatures of all the sites over all the years, suggesting it is also heavily recharged by groundwater. Its temperatures never rose above 25 degrees: the highest temperature was 24.6 degrees for one hour and 15 minutes during the night of July 19th.

Overall the warmest water temperature year for trout was 2011 because it had the highest percentages of water temperatures above 25 degrees for all sites. The most consistent, in terms of all of the sites having similair percentages, year would have to be 2013 because all the sites were above 25 degrees for less than half of the summer. The percentages of cooler water was higher the further downstream the measurements were taken in 2012. Therefore it is difficult to interpretwhich summer was better for trout in terms of water temperatrue, 2012 or 2013. Overall, when comparing locations, the Outlet sites had the most time above 25 degrees in each of the studied years, and then the percentages continued to decline the further downstream the measures were taken in 2012 and 2013. In 2011, however, the percentage of above 25 degrees decreased significantly from the Outlet site to the Willow St. then at the Downstream site it was only slightly less than the Outlet site.

The summer of 2011 supported the hypothesis that during times of lower discharge, air temperature influences water temperature more than when at higher discharge. This pattern was seen at two of the three studied sites. This is also the only summer where the three main sites were the only ones under study. The Willow St. and Downstrem sites both had their water temperature peaks, 30 and 30.9 degrees Celsius respectively, on the 22nd of July, which was also the hottest day of that summer with the air temperature reaching 36.1 degrees Celsius and a minimum of 25 degrees. The Outlet site had a high maximum water temperature of 29 degrees C on the 22nd ,but the highest the water temperature reached that summer was on the 20th, 23rd, and 24th of July with a maximum of 29.3 degrees C for all three days. These were the 4th, 3rd, and 11th warmest days of the summer respectively. The daily maximum discharge for the 20th and 22nd was 14 cfs, for the 23rd it was 15 cfs and the 24th saw 16 cfs. All the days with the highest water temperature for each site and relatviely high air temperatures also had low discharge. Another interesting patteren is that all three sites had nearly one degree Celsius difference in their maximum water temperatures. This started with the lowest being the Outlet site and climbing about a degree every site downstream fromthat location. The Outlet site having the lowest of the three temperatures can simply be explained by the cooler water being discharged and lowering the water temperature of the closest site. Although the Willow St. site to the Downstream site difference is more difficult to explain, it could have been that there was more shade at the Willow St. site, or that there was more groundwater recharge than at the Downstream site.

Unlike 2013, the summer of 2012 did not support the hypothesis of the air temerpature affecting water temperature during times of low discharge. Air and water temperates for 2012 were not as correlated on the maximum air temperature day for the summer, and water temperature maximums for the summer for each site. The peak water temperature for the Outlet site during the summer of 2012 was 29.5 degrees C on July 8th which was the same day as the peak for the Willow St. site, andwas 28.9 degrees. The Downstream site reached its peak on the 12th of July, with 24.2 degrees C, and the Drain Way site did not get placed into the river until the 18th of July when its peak was reached at 25.2 degrees C.. Air temperature for the 8th and 12th were not particularly warm, with 30.6 degrees being the maximum temperature for both days. The highest air temperature for that summer came on the 18th of July when the Drain Way's peak was recorded. For all three days, the 8th, 12th and 13th, the discharge was about the same with the 8th having the highest at a maximum of 13 cfs and the 12th and 18th both had a maximum of 12 cfs. On all of the days that had peak summer water temperature there was also low discharge and relatively high air temperatures which supports the hypothesis of the air temperature having a larger efffect on water temperature during low discharge conditions.

During the summer of 2013, all of the sites have a peak water temperature on the 18th or 19th of July when the maximum daily discharge is only 12 and 19 cfs respectively, a rather low amount. This peak comes on the 5th and 6th day of an eight day period with no precipitation. These two days had the same maximum air temperatrue, 32.8 degrees Celsius, and minimum air temperature, 22.8 degrees Celsius. They were also the warmest days of the summer for 2013, supporting the hypothesis that at lower discharges the air temperature has a larger effect on the water temperature.

4.4. LOW WATER TEMPERATURES

During the summer of 2011, all three of the sites had the lowest water temperature recordings on the same day, June 17th, although the lowest temperatures are very different for each site. The Outlet site had its lowest temperature measured at 21.2 degrees C, while further downstream the Willow St. site had a much lower temperature of only 19.4 degrees C, andthe Downstream site recorded 20.8 degrees C. On June 17th ,the maximum air temperature was 24 degrees C with a minimum of 16 degrees C,which was about an average for that summer. The daily maximum discharge for June 17th was 196 cfs which was amoung the highest for that summer. This supports the hypothesis because on an average air temperature day the lowest water temerature was recorded during one of the highest dicharge times. Therefore discharge has a bigger impact on the water temperature than air temperture has on the 17th of June.

The preceeding summer, 2012, had the two upstream sites, Outlet and Willow St, record similar dates of the lowest water temperature, but the temperature itself is different from one site to another. For the Outlet site the lowest water temperature was 21.5 degrees C on June 28th and the 27th, for the Willow St. site with a temperature of 19.1 degrees C. The Downstream site's lowest temperature was 17.9 degrees C and was recorded on August 30th, which is also when the Drain Way site recorded its lowest temperature of 18.5 degrees C. The daily maximum air temperature for those days is around 27 degrees C, and the daily maximum dicharge for all the days is either 12 or 13 cfs.

The summer of 2012, in terms of lowest water temperature, also supports the hypothesis because all of the days with the lowest water temperature are also low discharge days. In this situation, however, the air temperature is relatively cool, and the air temperature is reducing the water temperature. The cooler air either cools the water temperature or does not raise it, like most summer days. The type of day also has an effect on the water temperature because water has a low albedo; so a sunny day will rise the water temperature more than a cloudy day with the same air temperature becauase the water will absorb the solar radiation from the sun.

All of the days with the lowest water temperature also had relatively cool daily maximum air temperatures. The discharge for those days is different than air temperature because the dicharge in general started off higher in the beginning of the summer then decreased. June 15th had a maximum daily discharge of 264 cfs, the 19th had 166 cfs, then later on in the year the discharges were much less with August 15th having only a maximum daily discharge of 13 cfs and the 16th having 12 cfs. The Outlet and Willow St. sites are good examples for validating the hypothesis because they were the lowest water temperature days for those sites and even though the air temperature was relatively low, the daily maximum discharge was amoung the highest of the summer for those days. On the other hand, the other two sites had their lowest water temperature days when air temperature was relatively low as well, but the discharge was also low. The Downstream site also had a low water temperature reading on June 15th, so the discharge could have an impact on that site too.

The comparisons between air temperature and water temperature, as well as discharge and water temperature, are important ones because it supports the idea of air temperature or discharge affecting water temperature at all. Figure 25 shows the postive correlation between air and water temperatures for all three years. The steepest slope is from the summer of 2013, which makes sense because discharge would have the least overall effect on the water for that summer because it was low for most of the summer. This means that the air temperature would have been the bigger factor on water temperature in 2013. The 2011 slope is only slightly more steep than the 2012 slope because 2011 had slightly cooler water temperatures over the whole summer. Figure 12 shows the maximum daily air temperature vs. the daily maximum water temperatures during low discharge days for all three years with 2013 also having the steepest slope. This shows how air temperature has a strong influence on water temperature during times of low discharge. As for discharge and water temperature, Figure 26 shows the comparison for 2011 and 2013. For both years there is not much of a trend until higher discharge, about 50 cfs, when there is a negative correlation. 2013 has a much steeper slope than 2011 because 2013 has the lowest water temperatures when discharge is high. Figure 27 shows discharge and water temperature for 2012 on a separate graph because its highest discharge, 50 cfs, is much less than the other two years, 300 cfs. It has the same principle behind it, there is not much of a trend until higher discharge, 20 cfs, which shows a negative correlation.

After running regression statistics on MS Excel on Figures 26 and 27, all of the relationships were found to be statistically significant. The lower the p-value, the more confidence there is in how statistically significant the relationship is between the two variables. All of the maximum daily 2013 air temperature readings vs. all of the maximum daily Outlet site water temperature readings had a coefficient of 0.93 and a p-value of 1.1455E-10. The 2012 air temperature vs. Outlet site water temperature had a coefficient of 1.41 and a p-value of 2.02317E-8. The 2011 air temperature vs. Outlet site water temperature had a coefficient of 1.30 and a p-value of 6.48355E-10. The 2013 discharge vs. Outlet site water temperature had a coefficient of -13.99, and a p-value of 3.40066E-6. The 2012 discharge vs. Outlet site water temperature had a coefficient of -2.29 and a p-value of 0.00028. The 2011 discharge vs. Outlet site water temperature had a coefficient of -27.37 and a p-value of 6.24172E-9. All of the air temperature vs. water temperature values were found to have a postive correlation because the coefficient was positive and were found to be statistically significant. The discharge vs. water temperature vaules all showed a negative correlation because the coefficient was negative and the p-vaules showed a statistically significance.

4.5. IMPLICATIONS FOR TROUT

A study by Krider et al. (2013) on streams in Minnesota, used linear regression models to determine the relationship between air and water temperature as well as the influence of groundwater recharge on water temperature. Krider (2013) had similar results in the groundwater discharge affecting the water temperature and air temperature relationship when streams have large amounts of groundwater input then the streams response to air temperature is less than the streams with little to no groundwater input. This means that when a stream receives more groundwater inflow then air temperature does not have as much of an effect on the water temperature of that river.

These are similar results to what the Musconetcong River is experiencing, except the groundwater inflow is replaced by discharge from Lake Hopatcong. The regression models created in this study show that the streams with a steeper regression slope and lower intercept are meteorologically controlled (Krider et al., 2013). Figure 25 shows an example of this because the summer of 2013 has a steeper slope and a lower intercept than the other two summers and is controlled more by the air temperature than discharge because the only high discharge is seen in the beginning of the summer.

Water temperature often has a large effect on the aquatic ecosystem (Buisson et al., 2007; Caissie et al., 2001; Gooseff et al., 2005; Hari et al., 2005). Water temperature impacts the dissolved oxygen levels of the water, chemical processes in the river and, most importantly for this study, aquatic flora and fauna behavior such as mortality and growth rates (Caissie et al., 2001). Dissolved oxygen was not measured in this study but it can be esitmated based on the highest water temperature of about 31 degrees C. The Canadian Council of Ministers of the Environment (1999) says that for warm freshwater bodies there must be a minimum of 5.5 ppm concentration of dissolved oxygen. Since the warmest recorded water temperature was about 31 degrees C the trout should not have a problem with dissolved oxygen levels because the amount of dissolved oxygen in a freshwater body can be 7.5 ppm (Clean Water Team, 2004). Specifically, this study focused on the importance of brown and rainbow trout mortality due to water temperatures greater than 25 degrees Celsius. High water temperatures can manifest in several ways, including directly being lethal for the trout or indirectly affecting the food supply which will adversely change the trout's feeding habitats (Gooseff et al., 2005). Trout are very susceptible to being affected by the changes in water temperature because their body temperature changes as their surrounding environment temperature changes (Gooseff et al., 2005). While this is true for all cold blooded animals, trout are more susceptible because trout ova have a healthly growth potential at water temperatures between three and 15 degrees C (Hari et al., 2005), and growth will stop completely above 18.7 to 19.5 degrees (Hari et al., 2005). Although the more sensitive juvenile life stages occur in spring (Hari et al., 2005) and this study takes place during the summer, temperature is still an important factor for the survival of trout in all stages of life. The summer is when most of the variations in water temperature occur because of the changes in the depth of the water, solar radiation, cloud cover, and low flows (Caissie et al., 2001).

The water temperature often rises above the incipient lethal temperature of 25°C at all sites on the main stem of the river, suggesting that the trout need to find small pools to use as refugia from the high water temperatures and low dissolved oxygen levels (Elliot, 2000). Some of the smallest pools will not work as well at warmer temperatures and may disappear altogether (Elliot, 2000). Some of the larger pools are possibly large enough for the temperatures to be cool enough for the trout to stay in the deepest point of the pool, while some move toward the surface at night when the pools cool slightly (Elliot, 2000). The deepest point of the pools have the lowest temperatures, but also the lowest level of dissolved oxygen (Elliot, 2000). Therefore it would seem that trout are more susceptible to higher temperatures than to lower dissolved oxygen levels.

There are many factors controlling trout survival in addition to water temperature, such as predators, prey, proximity to competitiors, cover, and habaitat features (Matthews et al., 1994). The trout may be seeking cover from predators in the deepest part of the pool to be less vulnerable (Matthews et al., 1994). Temperature could be more of an important factor for trout survival than dissolved oxygen because trout were found in an area of lower water temperature, but also lower dissolved oxygen (Elliot, 2000) and the concept brings up a new strategy for the management of trout. The creation of these refugia pools to connect to the hyporheic zone could aid in the trout population and lessen deaths (Elliot, 2000). These pools have also been known to help trout in the winter habitat during periods of high flow (Elliot, 2000). This would be a year-round investment in the health of the trout population.

4.6. LAKE HOPATCONG WATER MANAGEMENT

The Lake Hopatcong management want to keep as much water as possible in the lake for their recreational uses, so increases in discharge is often not an option for cooling down the river. The creation of cool water refuges can help the trout and can be done in a few different ways; an influx of cool water from tributary streams or surface springs (Tate et al., 2006). There is a cool-water tributary stream which never rose above 25°C in the summer of 2013, and would make a good influx of cool water. The only problem is that it already feeds into the river, and does not affect the temperatures which are still too high and the volume of water is too small to aid. There could also be an influx of cool water from the hyporheic zone groundwater and mix with the warmer surface water. (Tate et al., 2006). Riparian vegetation could be restored to buffer cool water streams against the effects of warmer air temperatures (Krider et al., 2013). The stratification of the pools is probably not possible without the use of a barrier such as large woody debris or a gravel bar to slow down parts of the river and allow it to stratify (Matthews et al., 1994). The barriers will slow down the mixing of the incoming cool water with the warmer water and allow the cooler water to sink into the pools. The barriers will also allow water cooled overnight, or during periods of lower air temperature or high discharge to sink (Matthews et al., 1994).

4.7. POSSIBLE SOLUTIONS

Large woody debris are needed in a river to perform key functions including the stabilization of bedforms and channel banks, dissipation of flow enegry, providing shade and cover for aqautic organisms and the formation of pools (Booth et al., 1997). Large woody debris is also found to retain nutrients in headwater areas and create aquatic and riparian habitat (Curran and Wohl, 2003). The loss of large woody debris will cause more rapid bank erosion, greater sediment fluxes, and the loss of heterogeneity in bed morphology (Booth et al., 1997). Previously large woody debris was manually removed from rivers because fish were thought to suffer from the large woody debris blocking their migration. Under commercial forestry permits in the 1970's and early 1980's, the removal of large woody debris was mandated (Booth et al., 1997). The relatively deep pools created by, and adjacent to, large woody debris are sought out by trout and other fish as refuge from possible predators, high flows and high water temperatures (Booth et al., 1997). The presence and location of large woody debris is the determinant of the formation of pools, with pool frequencies found to be two to three times greater than in large woody debris-free rivers (Booth et al., 1997). With the removal of large woody debris fish populations have been known to decline rapidly (Booth et al., 1997).

There are two main ways to reinstall large woody debris into a river. One is to place the unanchored debris into the river and allow the high flow events reorganize the debris, while the second is to constrct large woody debris jams into the river to simulate natural analogs (Booth et al., 1997). The first approach was done to rivers in Washington by introducing large woody debris with the purpose of it reorienting and incorporating iteslf into the system through natural fluvial processes (Booth et al., 1997). The study found that the placement of bare cylindrical logs, with no stems or rootwads, was not as effective as the addition of pieces with greater complexity (Booth et al., 1997). The placement of more pieces of large woody debris per unit length of river was also found to increase the effectiveness of the addition (Booth et al., 1997). Curran and Wohl (2003) also found that an increase in the amount of large woody debris would have a strong effect on flow resistance.

Depending on the pools location, the stratification can be enhanced by the water flowing at low turbulence (i.e. laminar flow) to prevent the mixing of warmer surface water. This flow pattern cannot be achieved near a waterfall, hydraulic jump, or other area of high water velocity (Matthews et al., 1994). The stratification can also be enhanced by the depth of the pool, with the deeper pools better able to retain cooler water, and is most noticable in the summer months during the afternoon and early evening (Matthews et al., 1994). These times are when water temperature is at its maximum, due to the delay in warming of the water from the air which is at its warmest in the afternoon. Matthews' study (1994) found that trout pefered to be in the deeper part of the pool even though the dissolved oxygen levels were lower. The study also showed that juvenile trout would use portions of the pool that were warmer, temperatures up to 24°C, even though cooler temperature areas were available (Matthews et al., 1994).

5. CONCLUSION

The Musconetcong River was classified by the NJDEP as Trout Maintenance Waters, meaning that the river must be capable of supporting trout throughout the year (Musconetcong Advisory Committee et al., 2003). This makes the river an important one to study the effects of water temperature changes on trout populations. The potential for temperature shifts to impact aquatic habitat in rivers is especially important in the summer, as the warm temperatures can stress populations and reduce available habitat. The summer is generally when most of the variations in water temperature occur because of the changes in the depth of the water, solar radiation, cloud cover, and low flows (Caissie et al., 2001).

As temperature is one of the most important factors in the growth and development of trout, these summer temperature changes can be life threatening (Hari et al., 2006). The summer measurements taken over the course of 2011, 2012, and 2013 show that air temperature and water temperature have a strong positive correlation: as air temperature increases it intuitively increases water temperature. The discharge and water temperature relationship is the opposite, with water temperature having an inverse correlation with higher discharge: with increased temperature there is a correlative (but not necessarily causal) relationship. Thus, at periods of low discharge, air temperature has a greater influence over water temperature than at higher discharge. Therefore more discharge may lower the water temperature, but Lake Hopatcong management is not required nor do they want to give all their water to the Musconetcong River. Consequently, a different approach must be taken. During the summer there are reports of trout finding pools to survive in when the water temperature rises above 25°C. The creation of these pools could help the trout survive through the hot summer and can be done by the addition of large woody debris. Large woody debris that has been removed from rivers because of periods of high flows or anthropomorphic reasons do not slow down the river or allow for the creation of these pools. Therefore large woody debris could be reintroduced into the river and allow for cooler pools to exist. For future studies, continued monitoring of the river water temperature at the current locations including the Tributary site would give another year of data to compare to the other years. It would also allow for the Downstream site to be compared between two years. The Tributary site would also need to be measured again because then the influence of the tributary could start to be assessed. Finding pools that trout use in times of high temperature would be another interesting place to put sensors to find if these pools are cool enough. Another idea is to make sure that the trout can get to the pools that are created or that already exist.

6. REFERENCES CITED

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7. APPENDIX: FIGURES AND TABLES

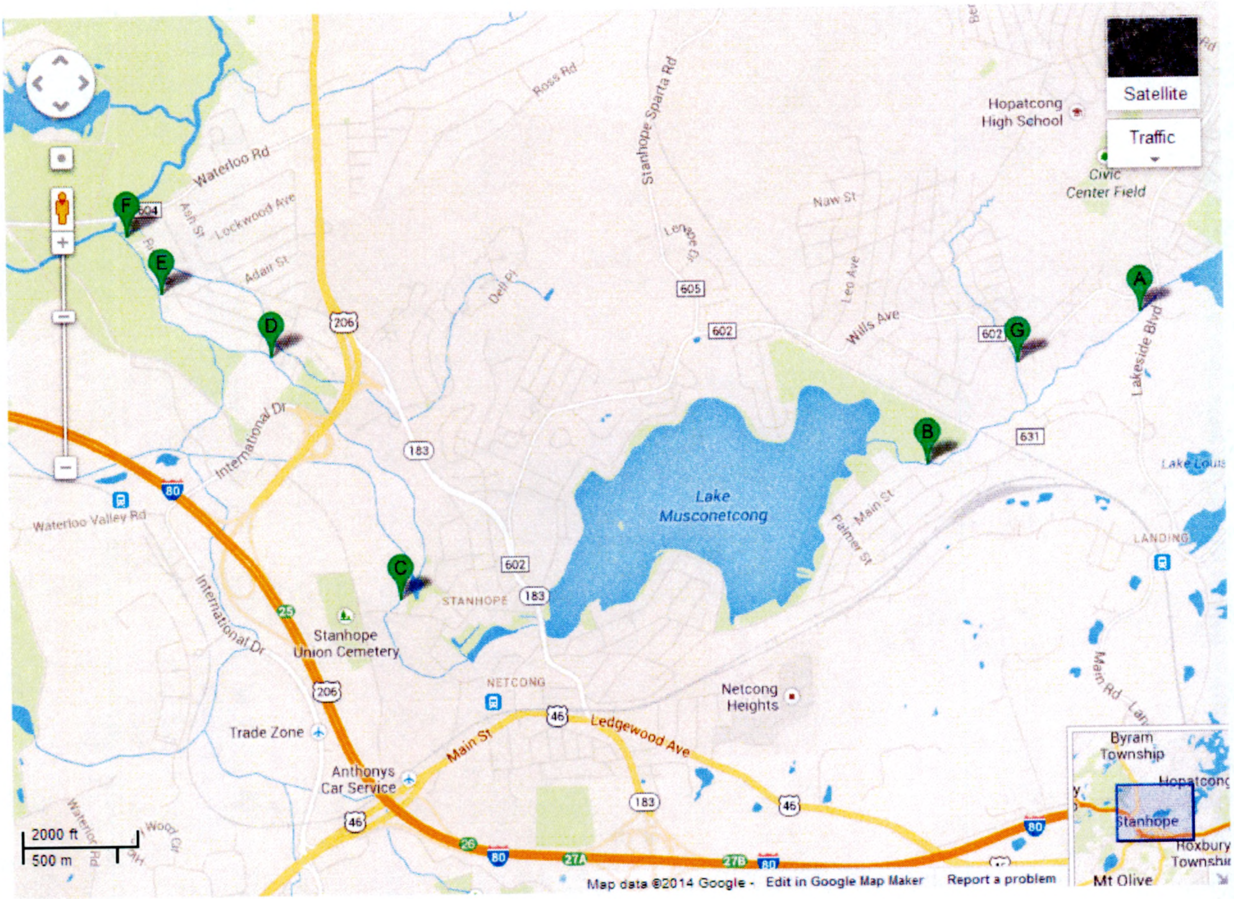


Figure 1. The seven different spots where the temperatures were observed over the three years; A is the Outlet site for all years, B is the Willow St. site for all years, C is the Downstream site for 2011, D is the Downstream site for 2012, and F is the Downstream site for 2013. E is the Drain Way site which was only measured in 2012 and G is the Tributary site only measured in 2013. The Outlet site is the most upstream location and the Downstream site is the most downstream location (Google Maps, 2014).

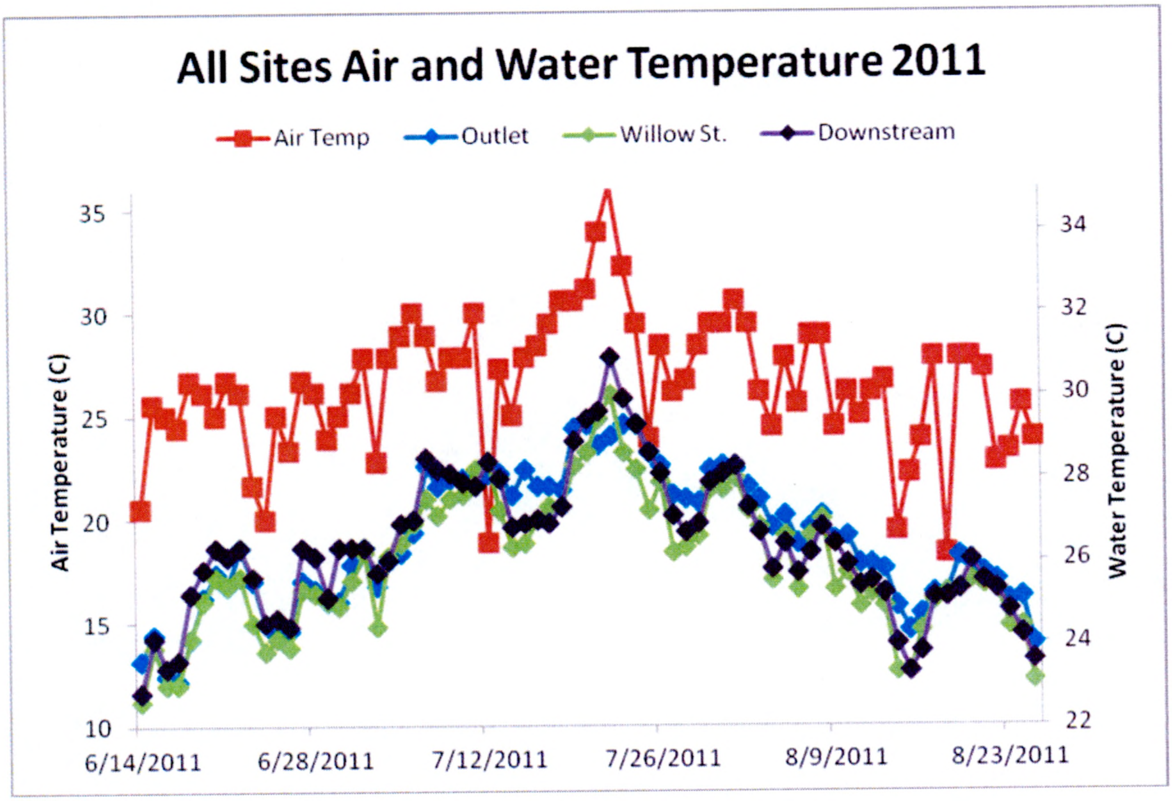


Figure 2. The daily maximum air temperature and water temperatrure for the four sites measured from mid June to late August 2011.

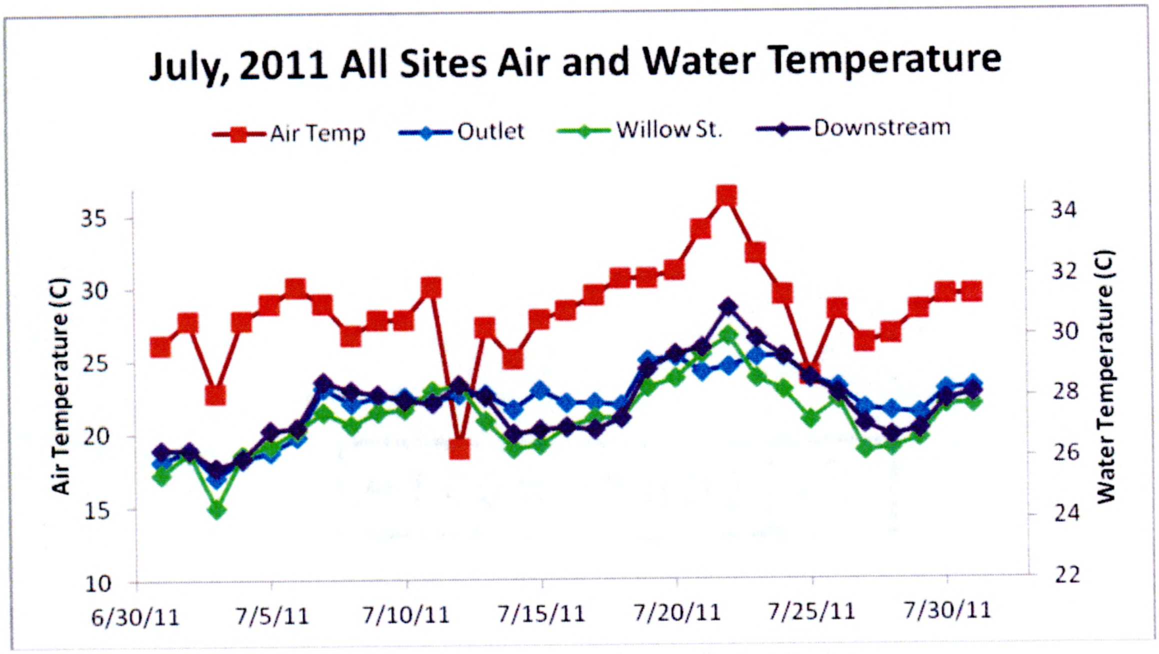


Figure 3. The daily maximum air and water temperaure measurements for July 2011, with the highest water and air temperature measured that summer on July 22nd showing up as a large peak.

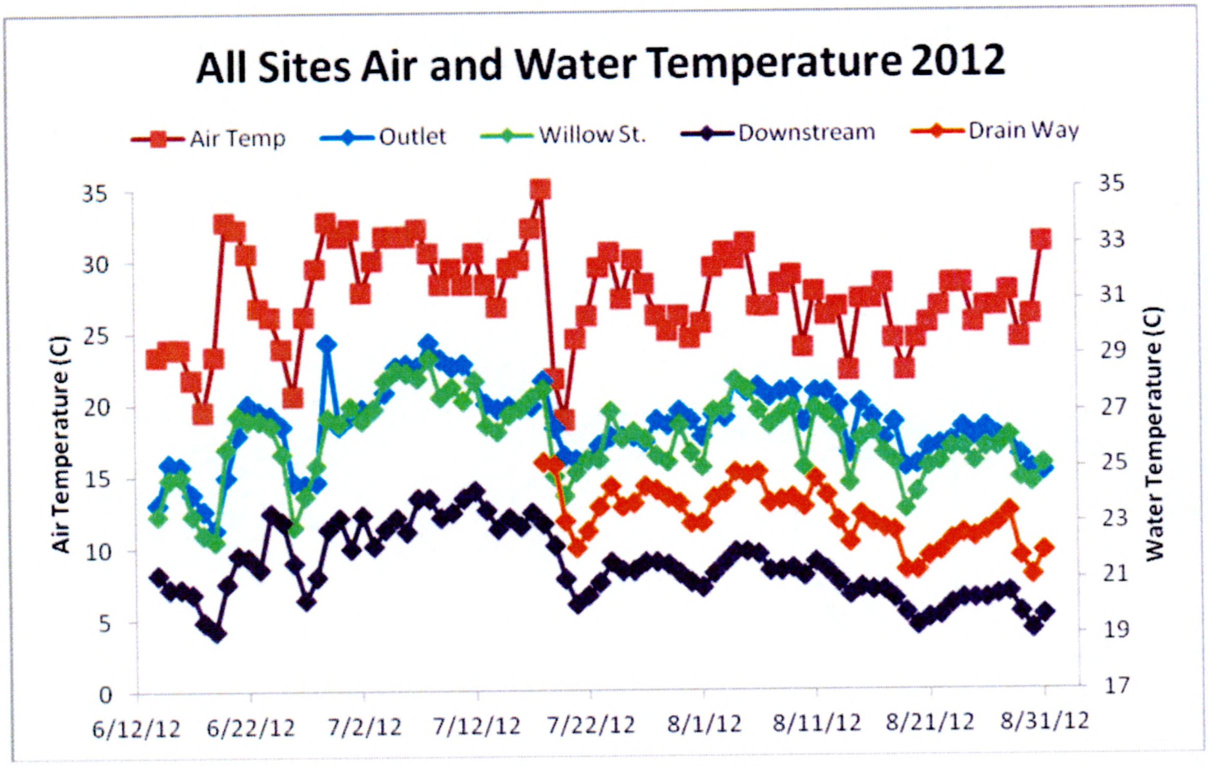


Figure 4. The daily maximum air temperature and water temperatrure for the four sites measured from mid June to late August 2012.

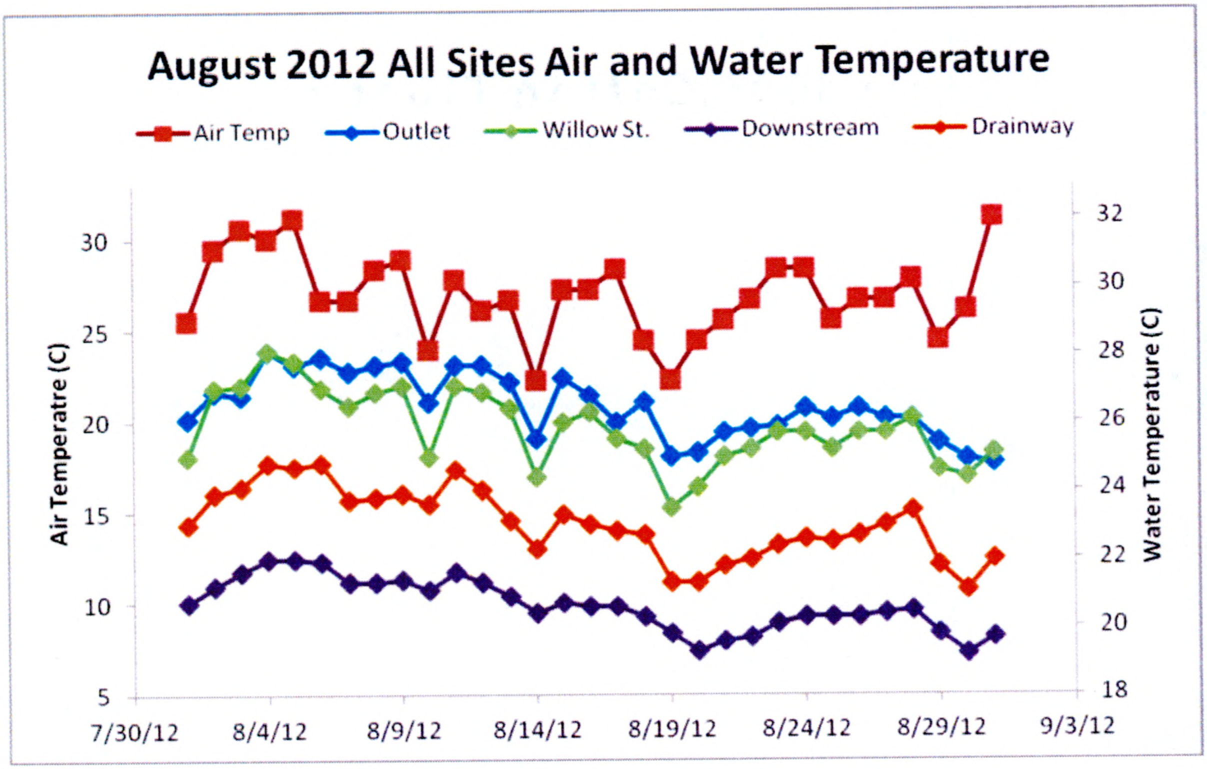


Figure 5. Similar to Figure 4, this shows the daily maximum air temperature and water temperatrure for the four sites measured in August of 2012. It is intended to show the correlation between the air and water temperautres because of their fluctuations during this month.

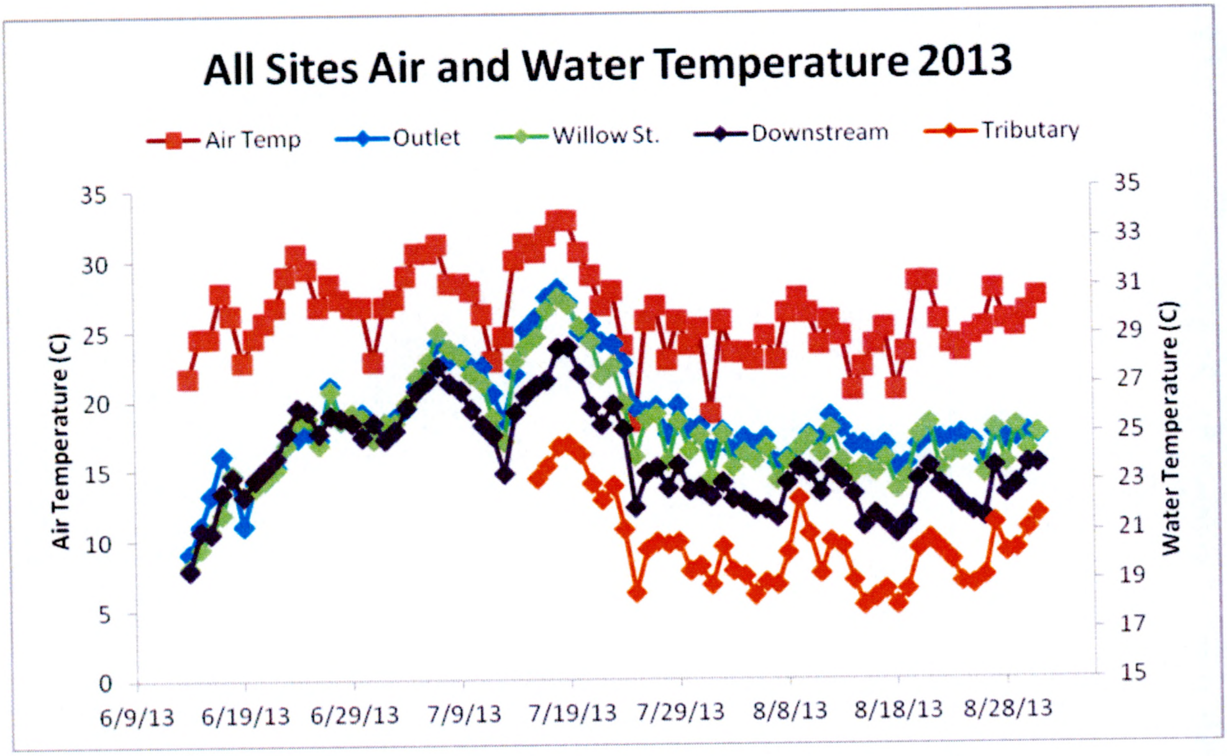


Figure 6. The daily maximum air temperature and water temperatrure for the four sites measured from mid June to late August 2013.

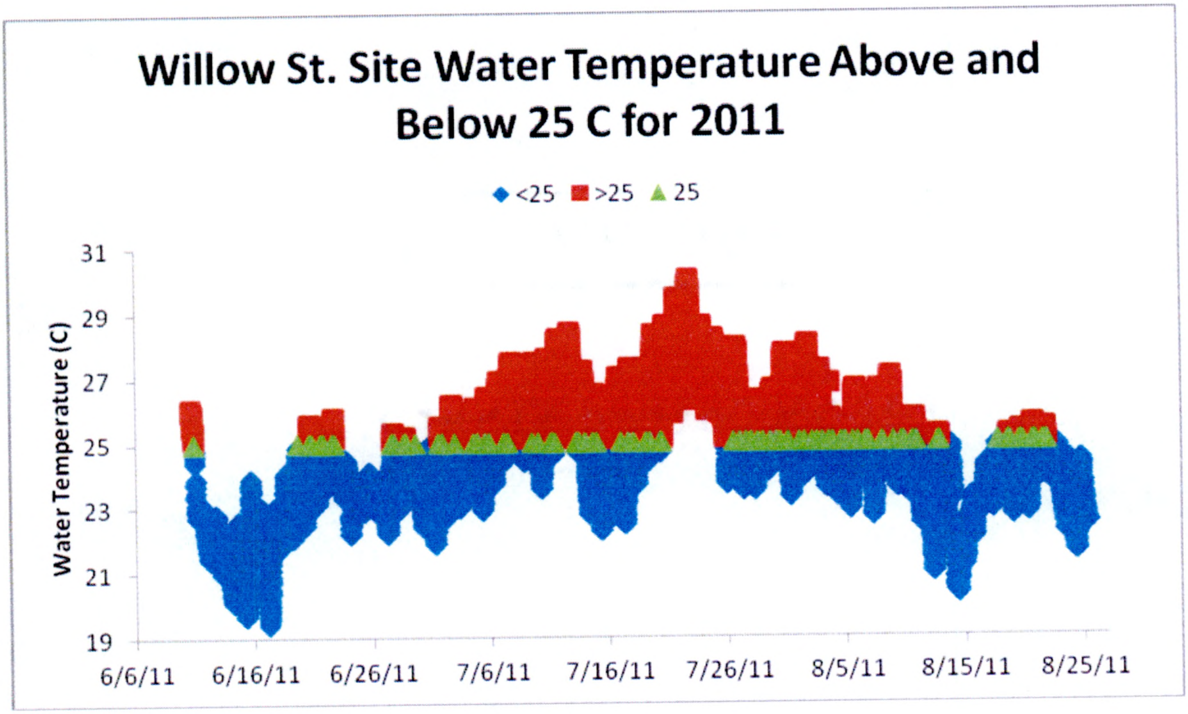


Figure 7. The temperature measurements taken from the Willow St site over the summer of 2011 with temperatures readings less than 25 degrees Celsius in blue, ones greater than 25 degrees are in red, and readings at 25 degrees in green. Here the July 22nd peak can be seen as well as almost 33 percent of the measurements taken being above 25 degrees.

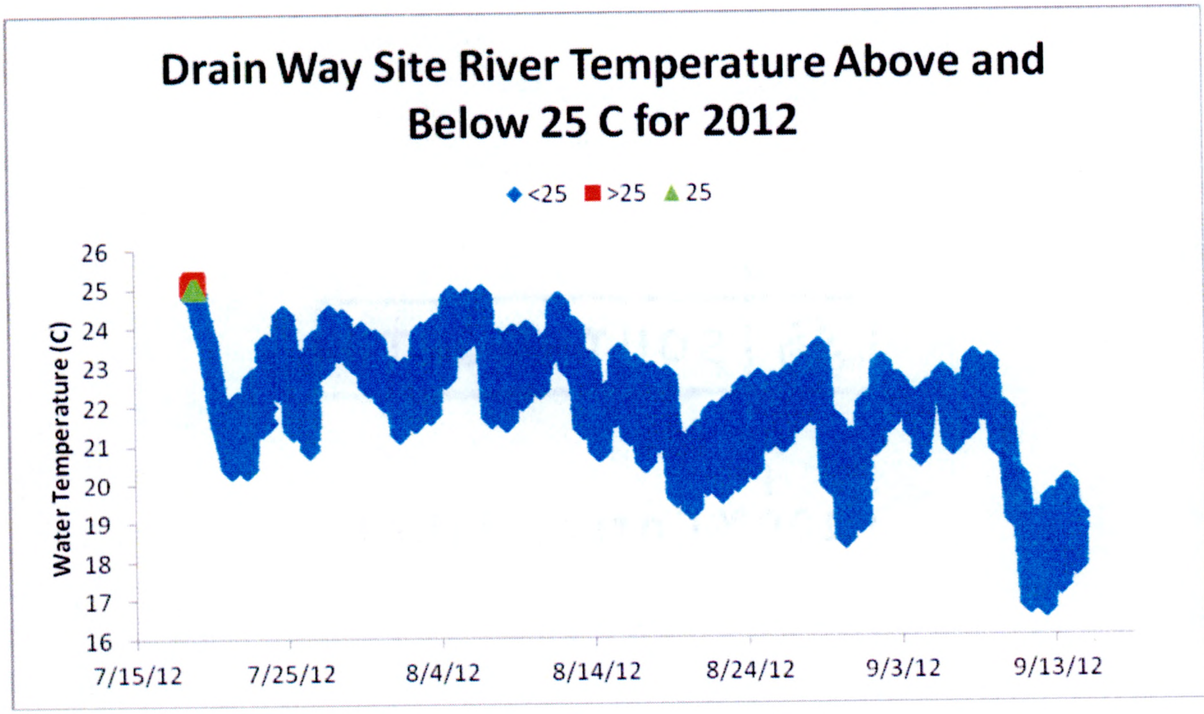
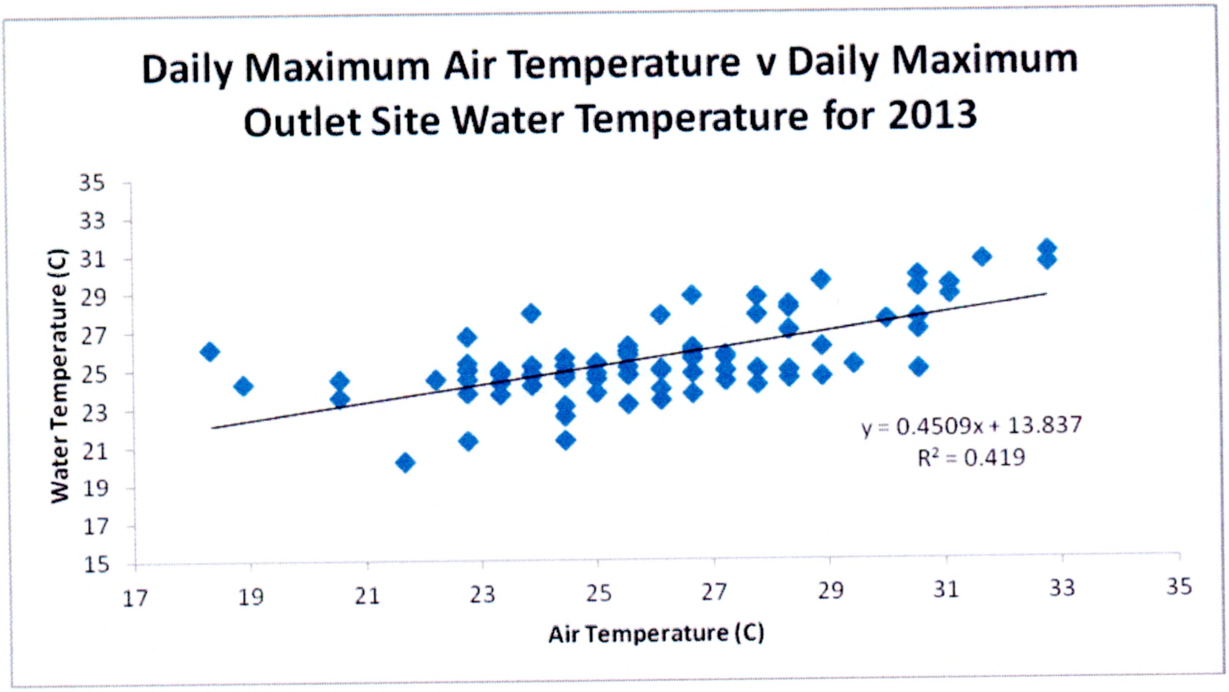
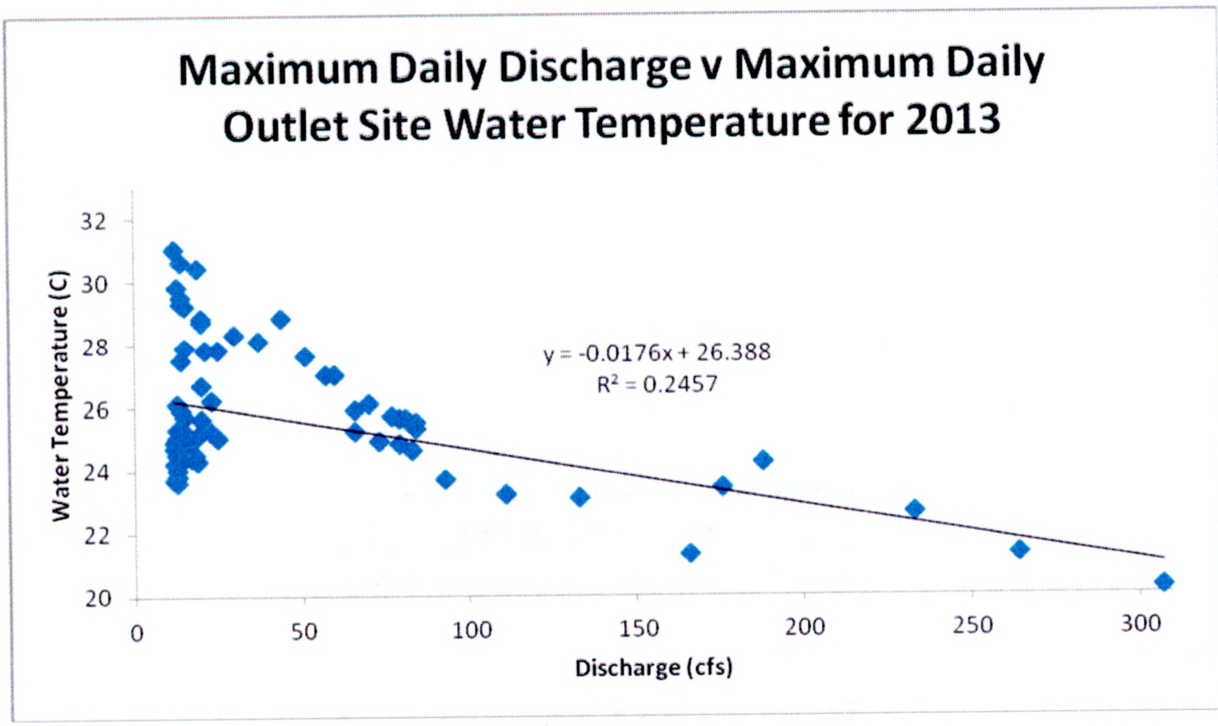


Figure 8. A graph of all the measurements taken from the drainway site over the summer of 2012 with temperatures readings less than 25 degrees Celsius in blue, ones greater than 25 degrees are in red, and readings at 25 degrees in green.





Figures 9 & 10. The effect of discharge and air temperature on water temperature seperatly in terms of their daily maximums for the summer of 2013. There is a strong postive correlation between air temperature and water temperature (Figure 9) while there is a negatve correlation for river discharge and water temperature (Figure 10).

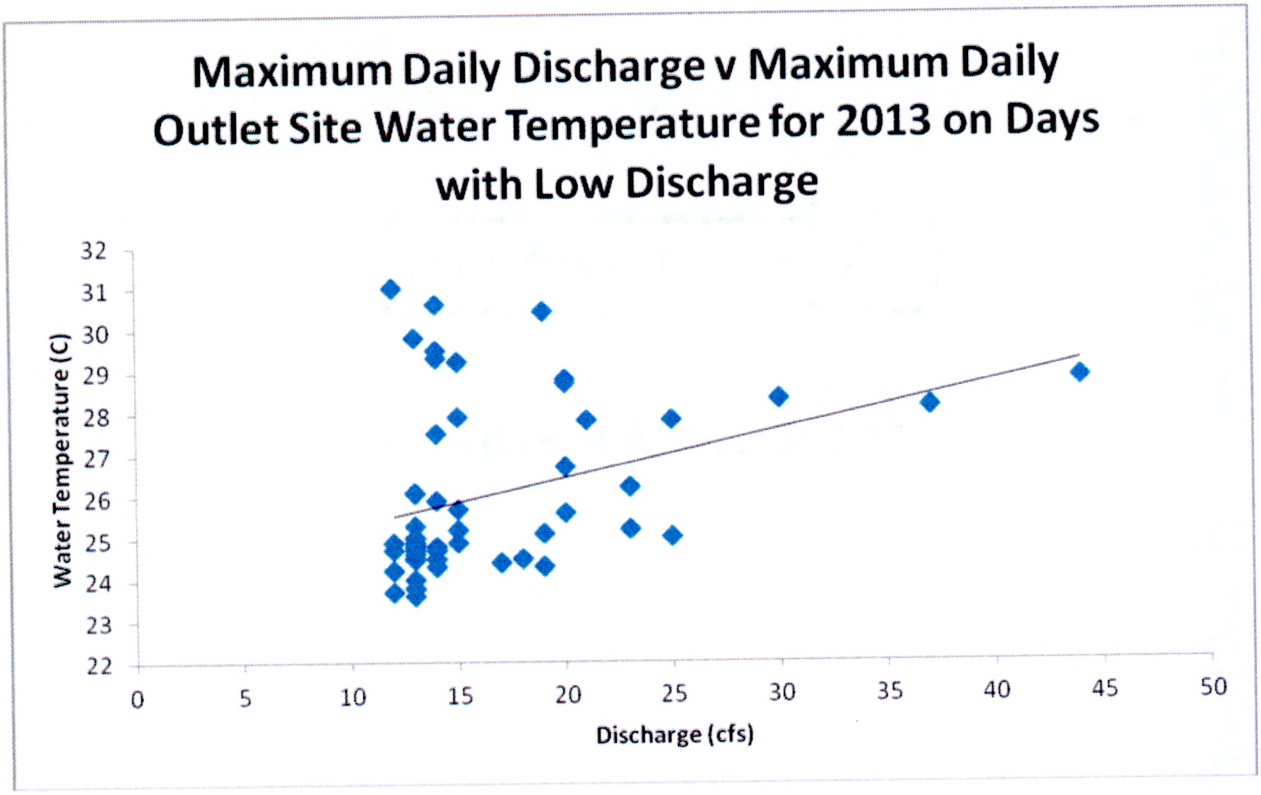


Figure 11. Daily maximum discharge vs. daily maximum water temperature for the Outlet site during 2013. This only shows the times when the daily maximum discharge is considered low, or below 50 cfs.

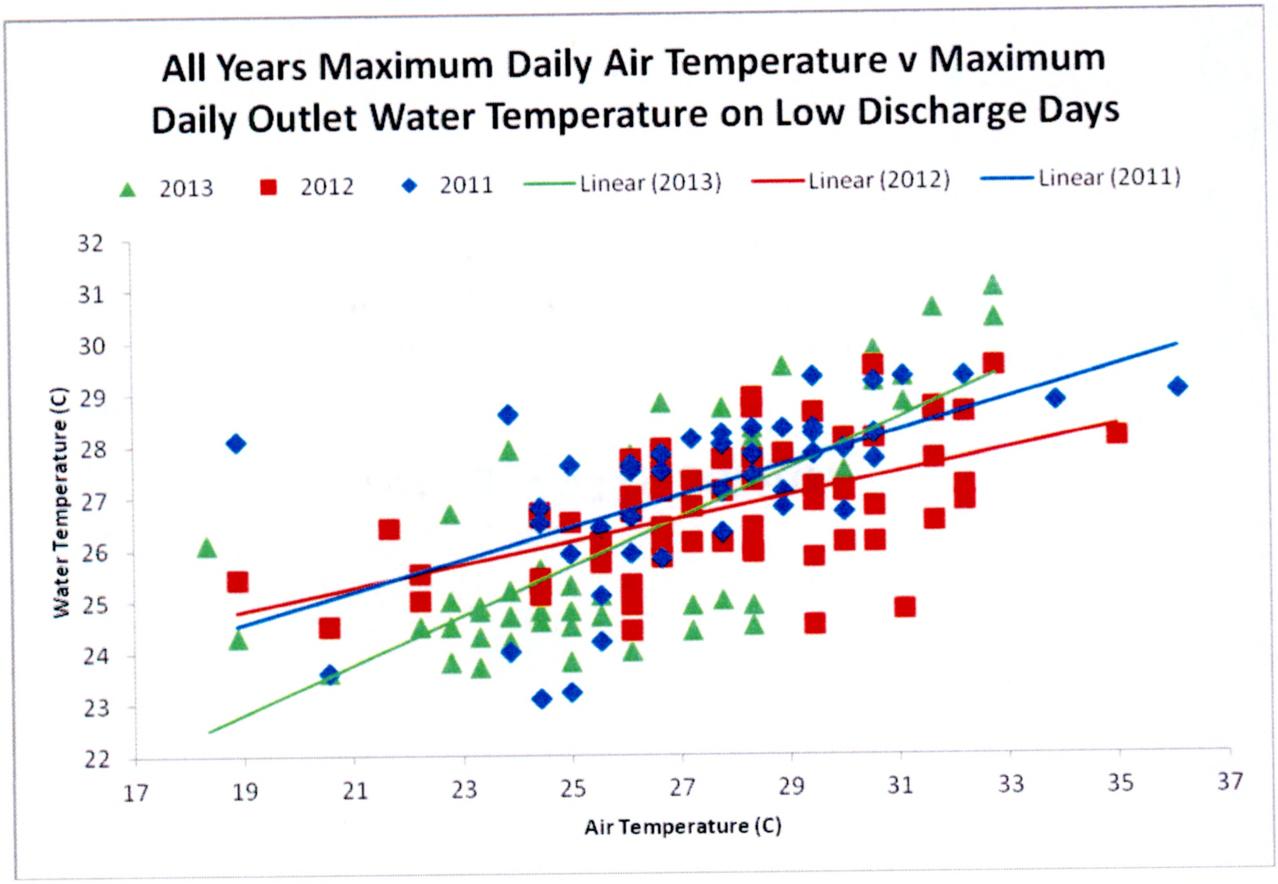


Figure 12. Daily maximum air temperature vs. daily maximum water temperature for the outlet site during all three summers at times of low discharge. The summer of 2013 is in green, 2012 is in red and 2011 is in blue. There is a stronger positive correlation between air temperature and water temperature at low discharge for 2013 than the correlation at all different discharges.

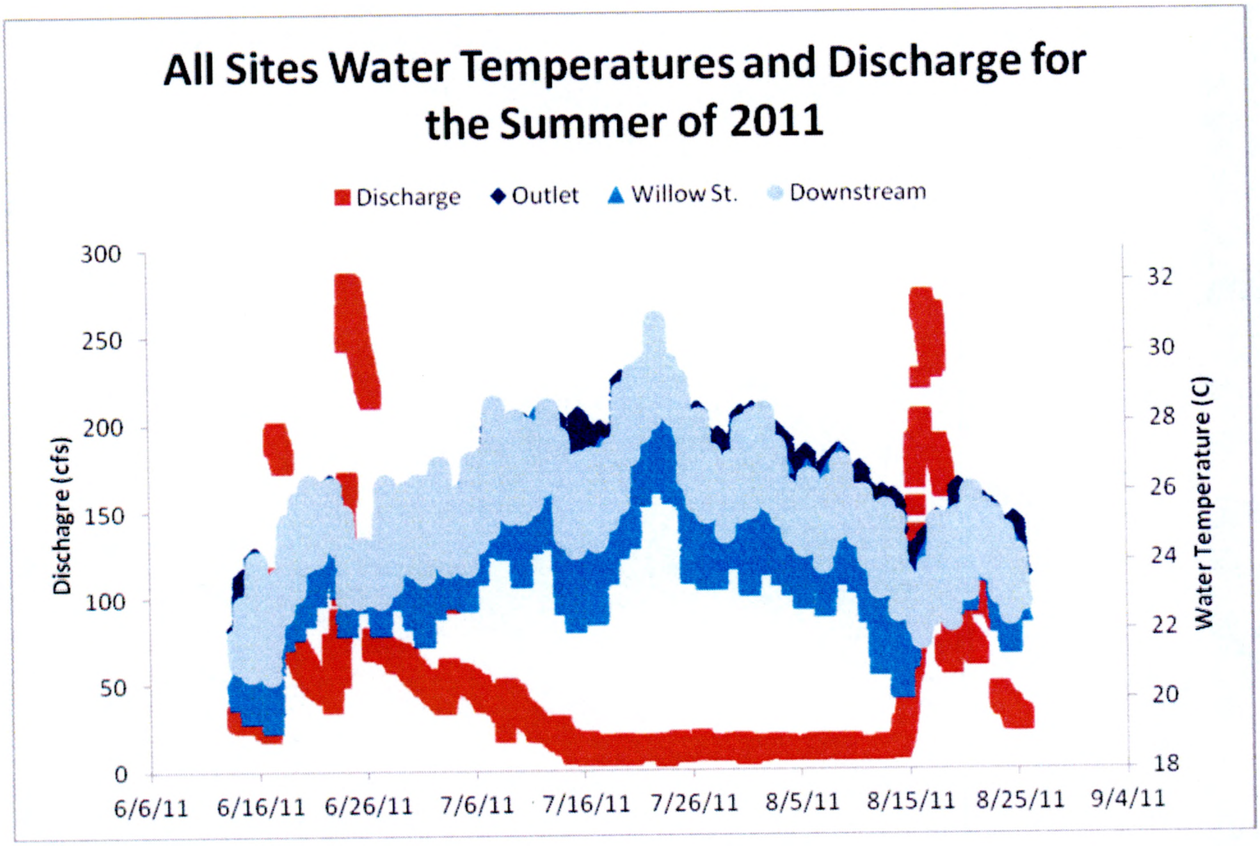


Figure 13. The entire data set collected for the summer of 2011 showing every site as well as the discharge. The discharge affects all the sites when it is higher than about 50 cfs, especially in the end of June and mid-August.

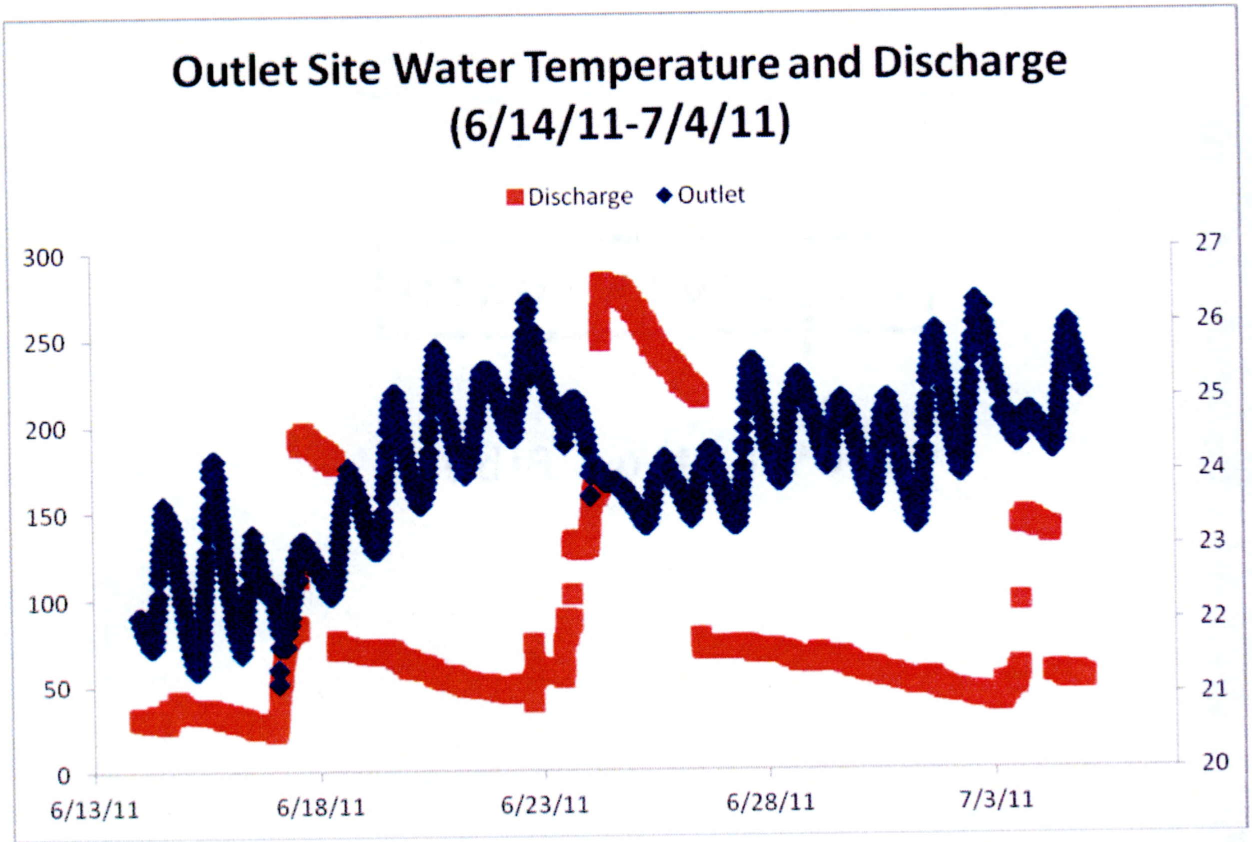


Figure 14. is when the discharge is at one of the two maximums for the summer and shows the effect on the water temperature of the outlet site. The initial discharge increase on the 17th also has a water temperature decrease and the opposite is true until the second discharge increase on the 23rd which is followed by a decrease in water temperature.

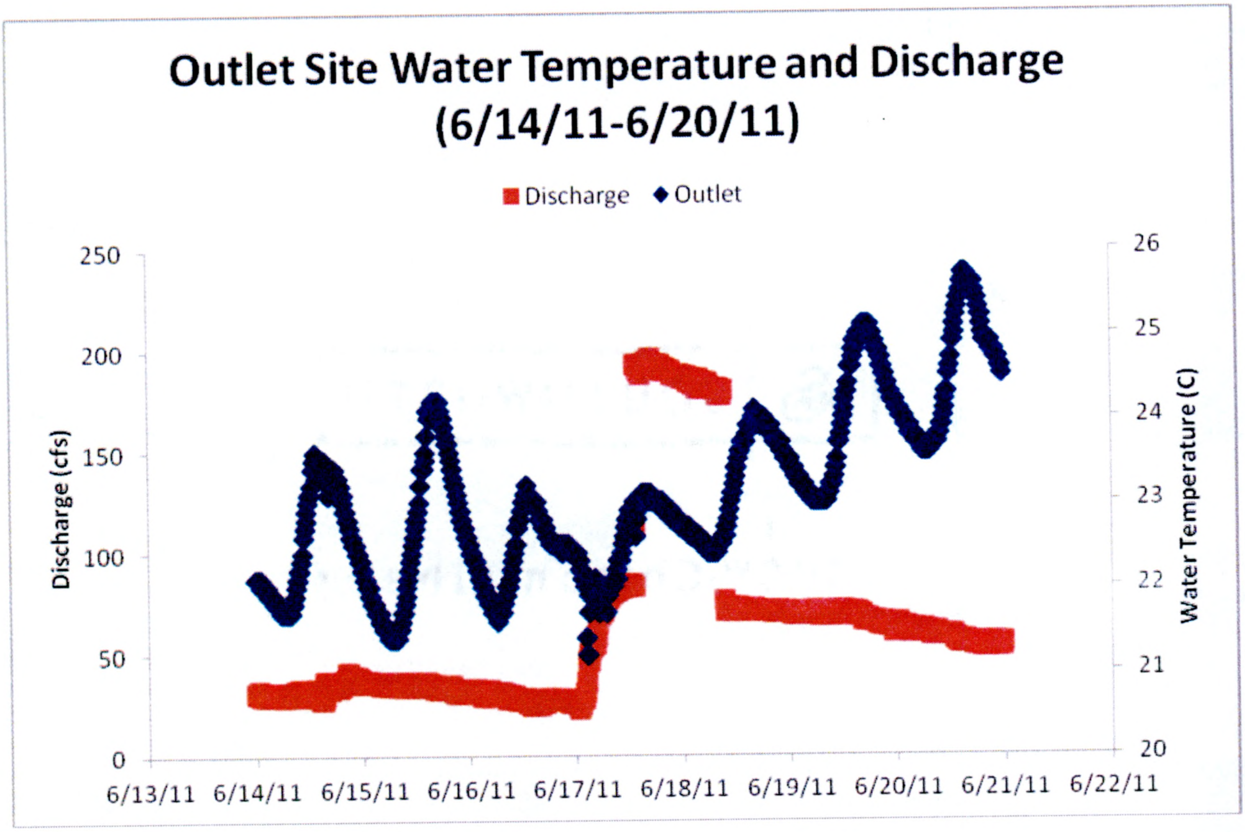


Figure 15. The initial, smaller, discharge increase for 2011 that occurs on the 17th of June. This also shows when the Outlet site water temperature starts to decreases within the hour of the peak starting on the 16th of June.

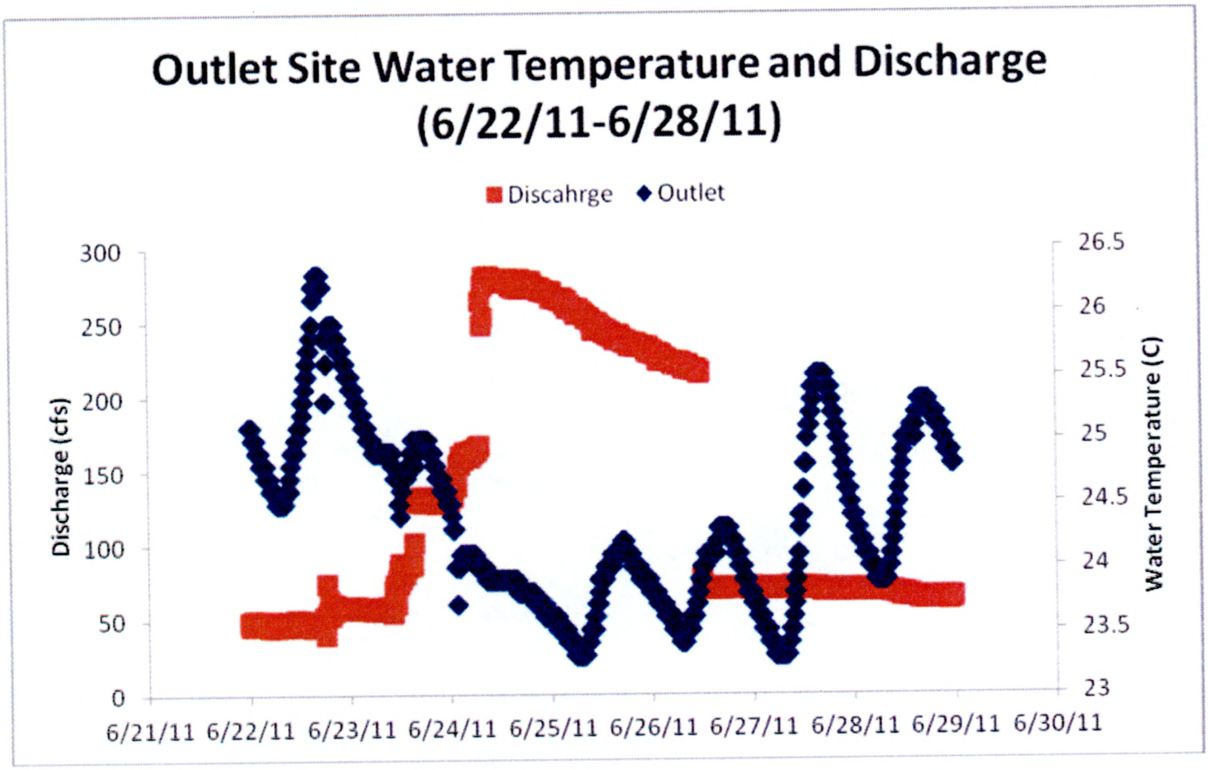


Figure 16. The maximum discharge peak for 2011 that occurs on June 24th. This also shows the Outlet site water temperature starting to decrease within the hour of the discharge starting to increase.

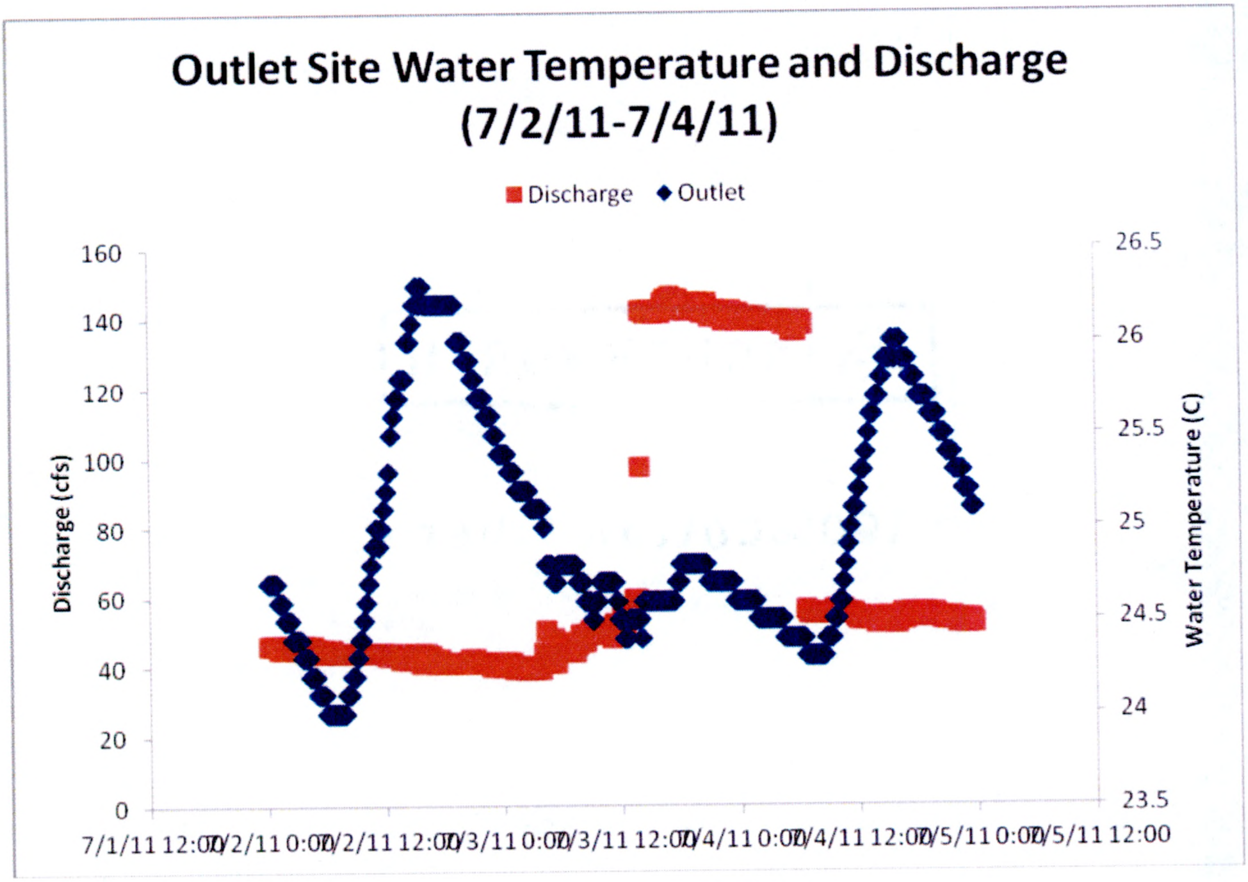


Figure 17. The small discharge increase in the begning of July, 2011 and the negative affect on the Outlet site water temperature can be seen within the hour on July 3rd.

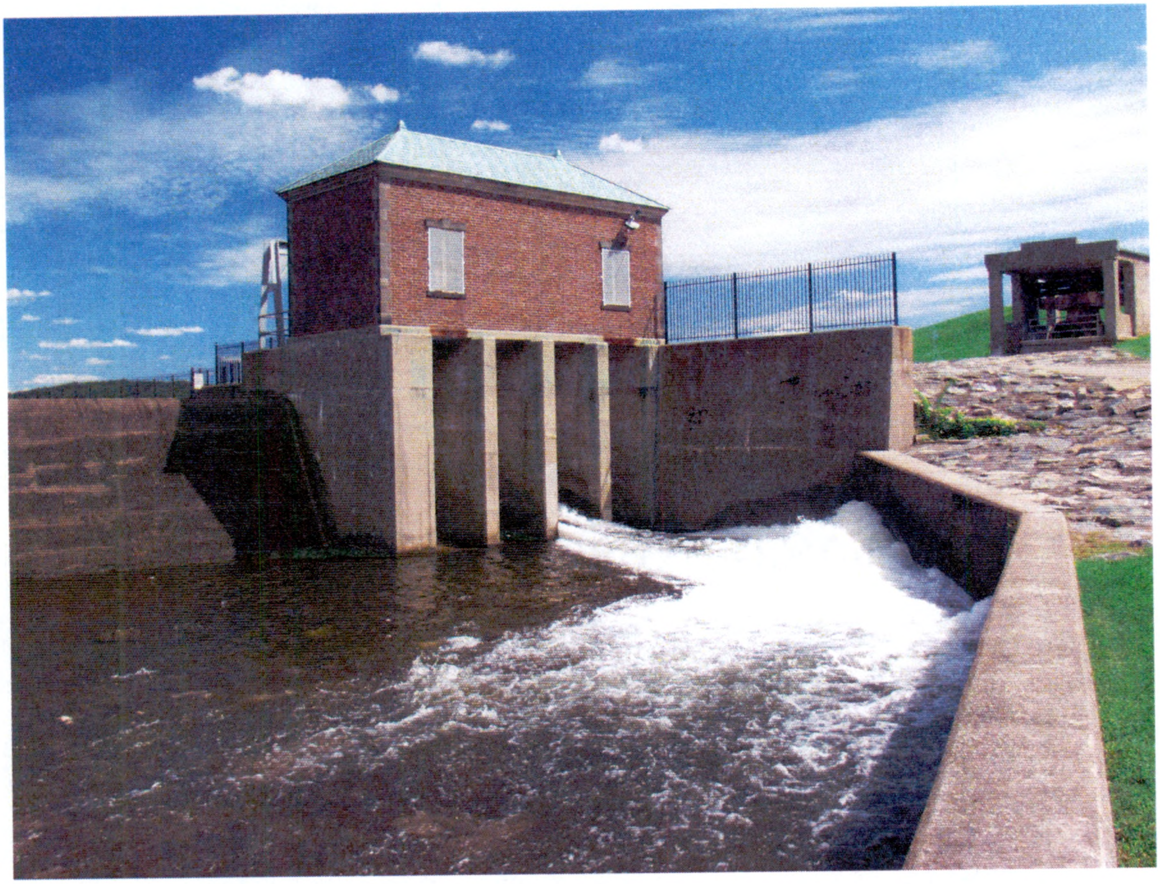


Figure 18. The Lake Hopatcong dam showing the slip over ledge on the right and the gates opened on the left with water flowing through into the Musconetcong River in the fall of 2003 (Lake Hopatcong Commission, 2013).

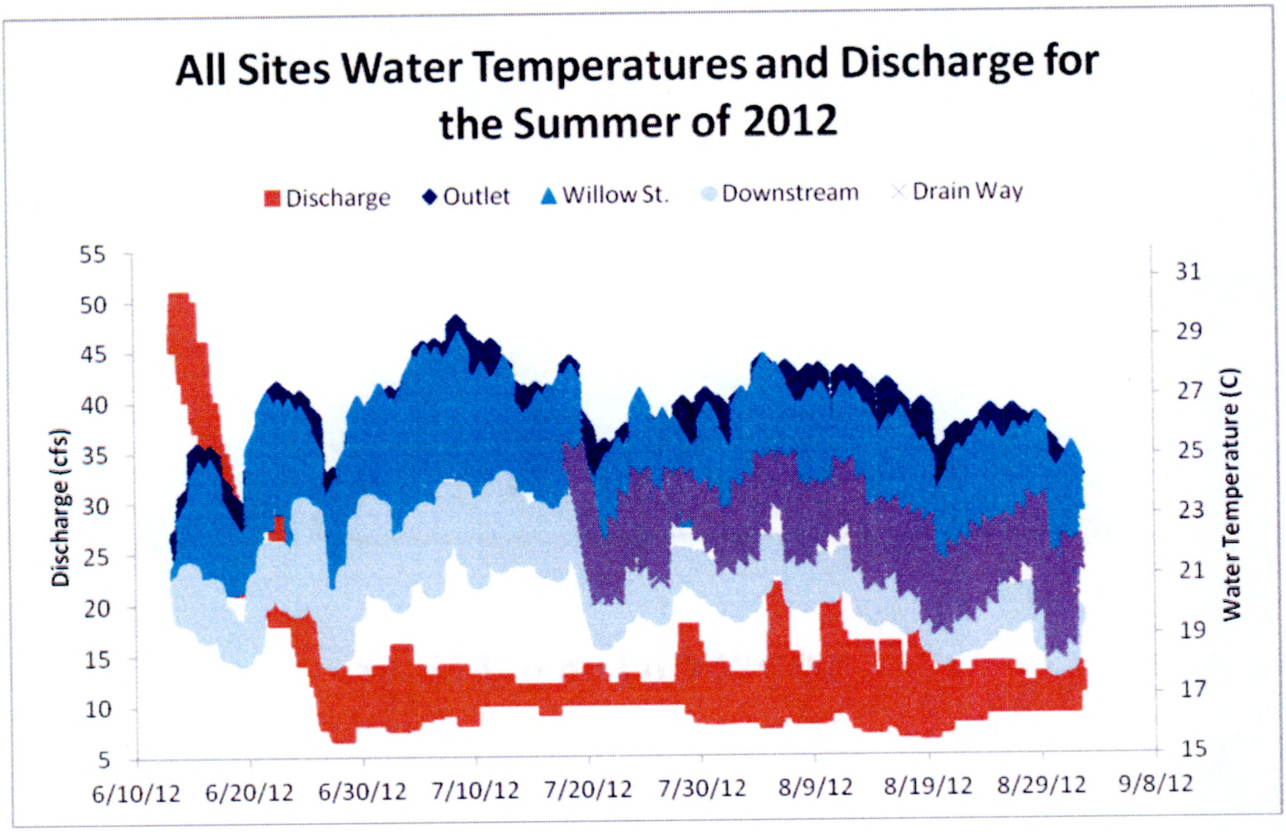


Figure 19. The entire data set collected for the summer of 2012 showing every site as well as the discharge. The discharge affects all the sites especially in the beginning of the summer during higher discharge.

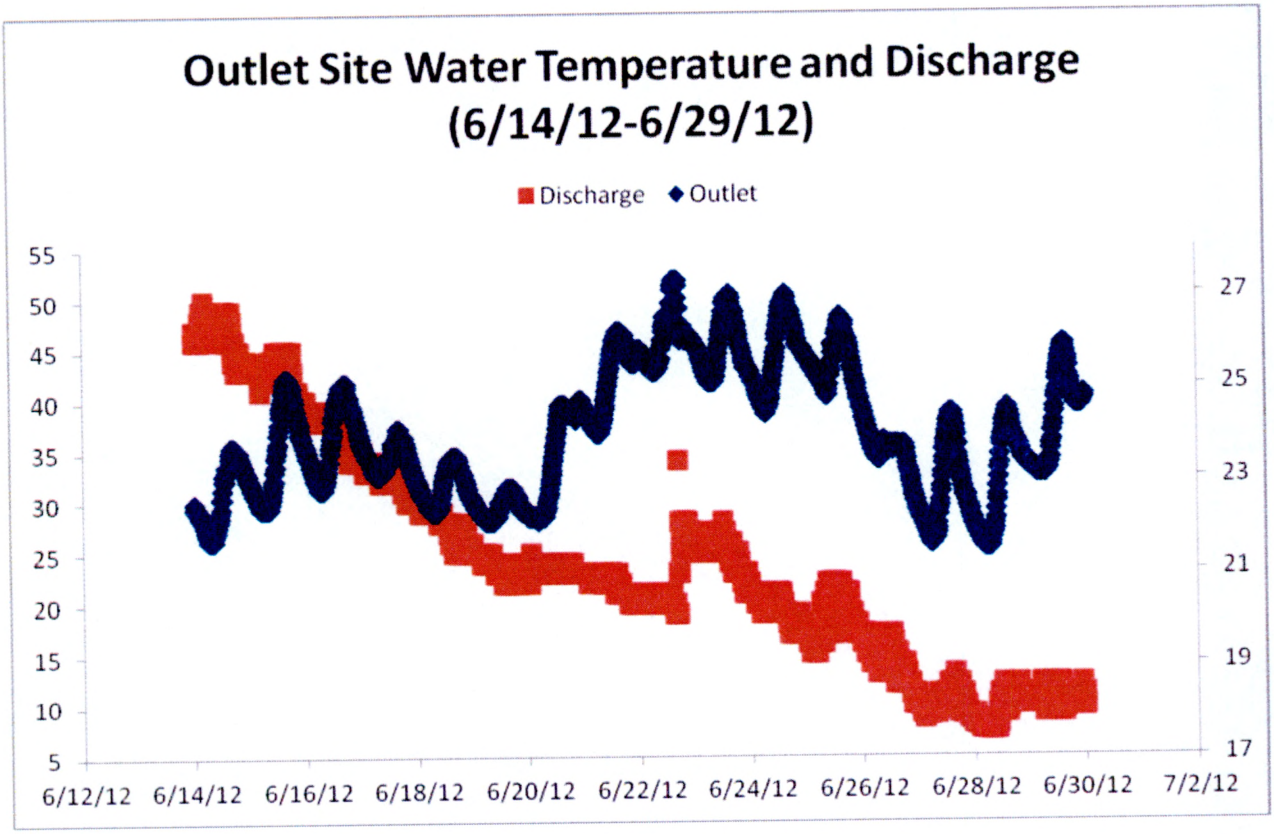


Figure 20. The time period when the discharge is at its highest for the summer and shows the effect on the water temperature of the outlet site. As the discharge rate falls, the water temperature rises.

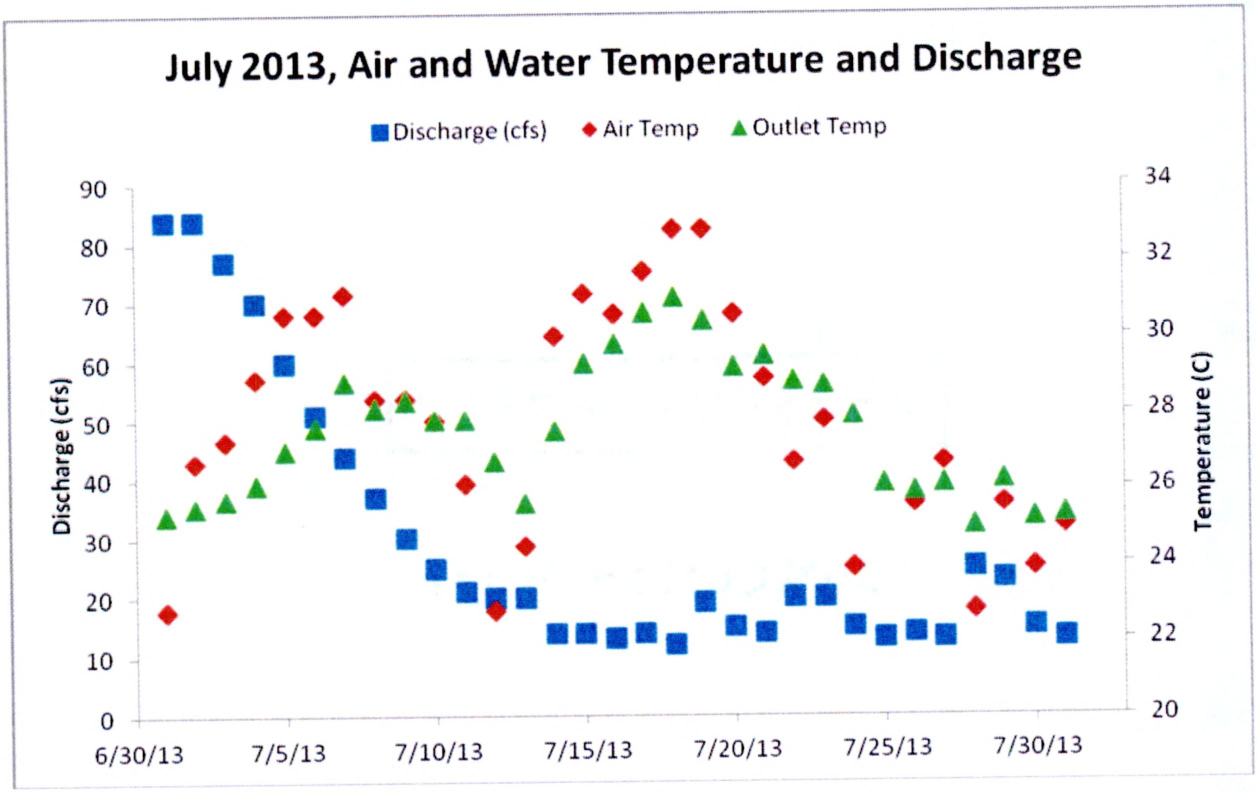


Figure 21. The water temperaute changes for the Outlet site, closest to Lake Hopatcong and furtherest upstream, over the course of July 2013 as well as the air temperature and discharge changes. Each point is the maximum unit measured for each day showing the strong trend between discharge and water temperature and a strong trend between air and water temperature.

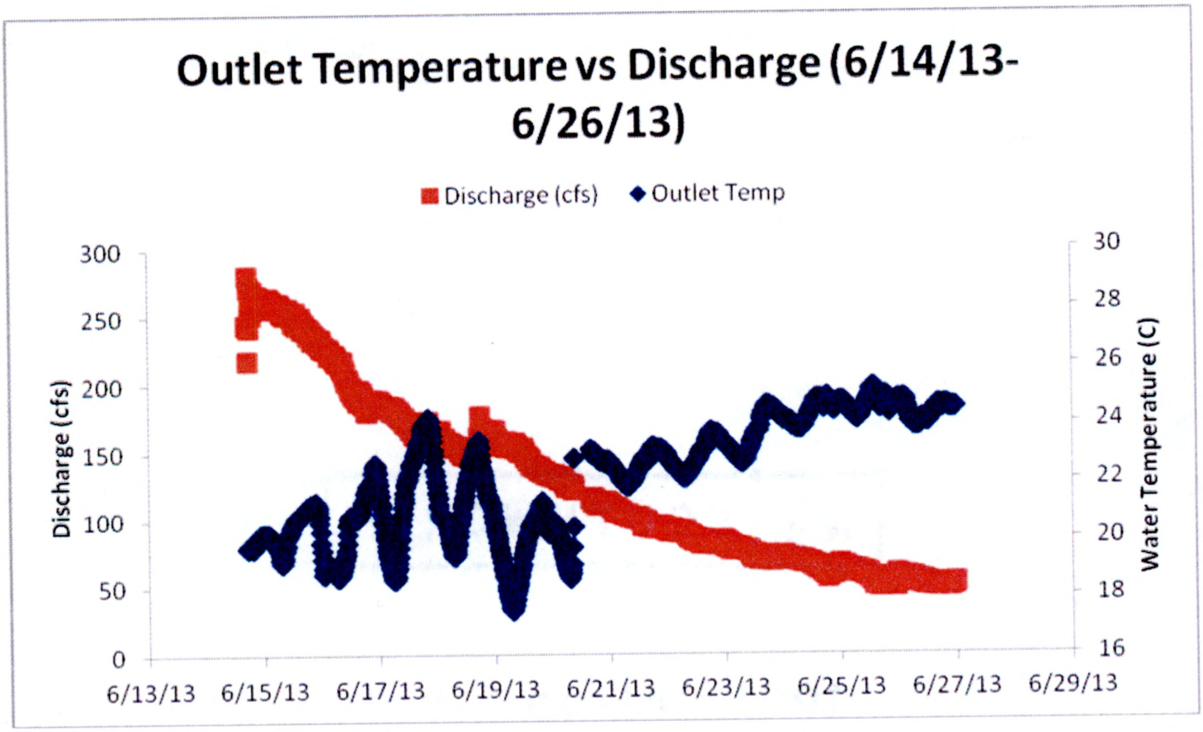


Figure 22. Illustrtes the strong negitive correlation between discharge and water temperature for the Outlet site, closest to Lake Hopatcong. This is the enitre data set for June 14th to the 26th showing every 15 minute measurement taken and how much cooler the site is when the discharge is higher.

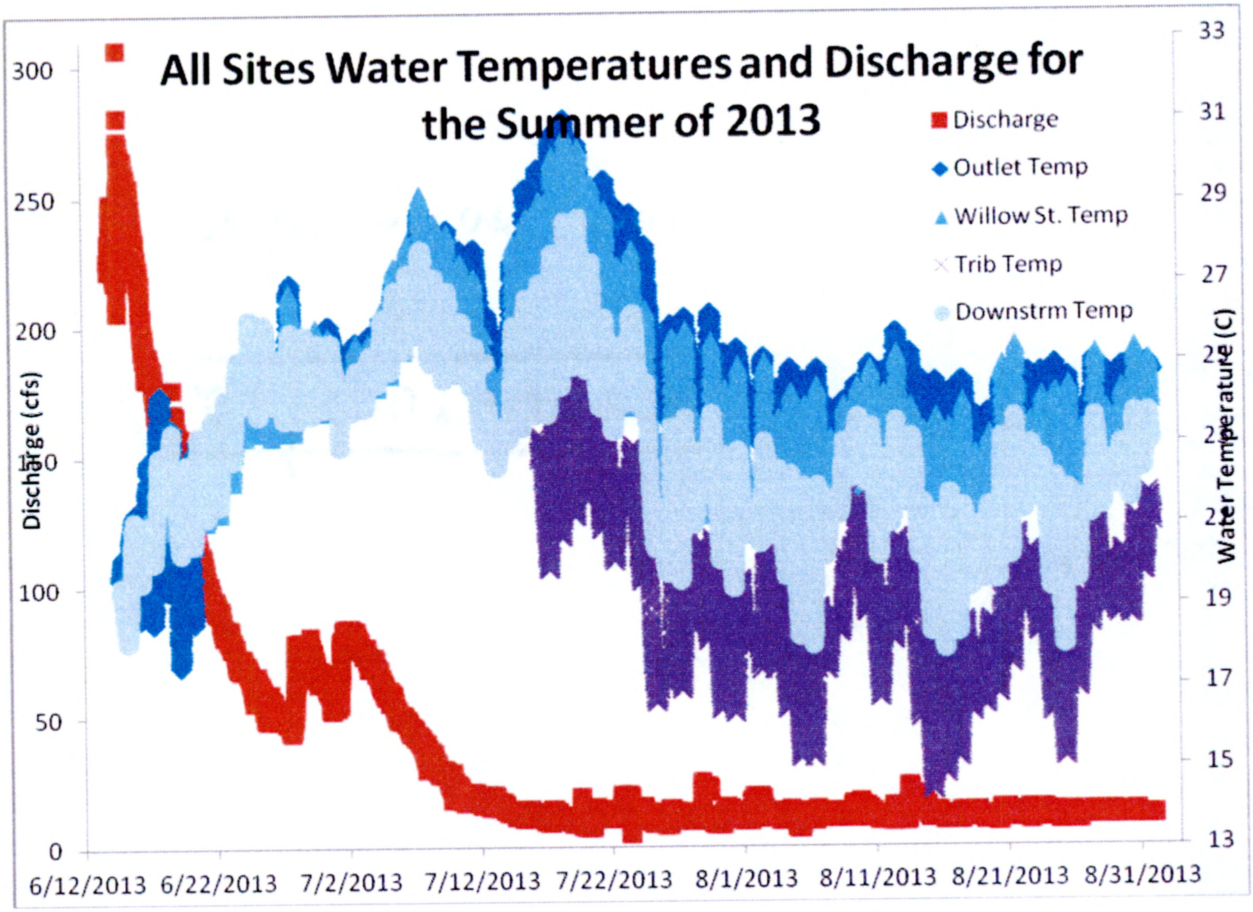


Figure 23. is the entire data set collected from the summer of 2013 showing every site as well as the discharge. The discharge affects all the sites except for the tributary because it runs into the river after the discharge point and the temperature is measured further upstream.

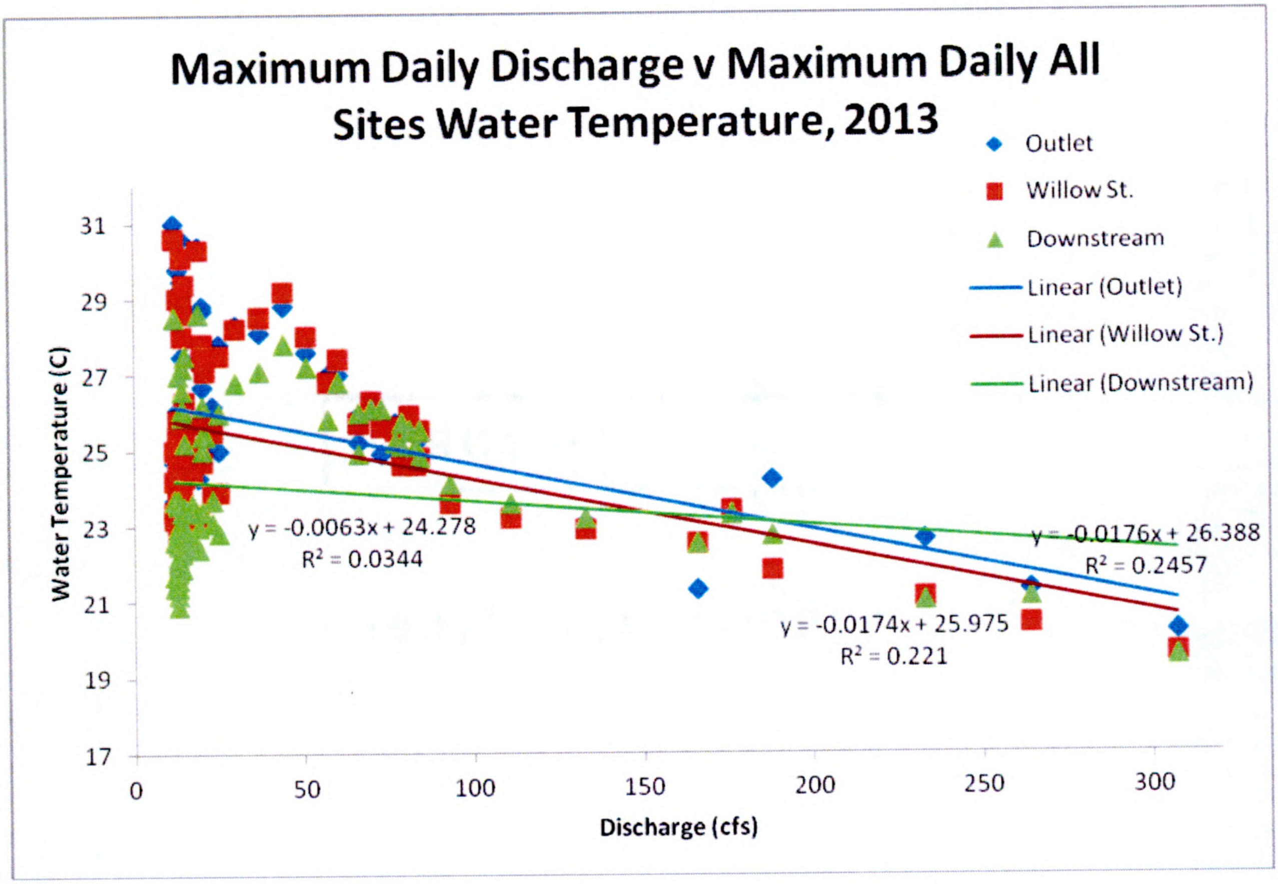


Figure 24. The maximum daily discharge vs. the maximum daily water temperatures for the Outlet, Willow St., and Downstream sites to compare the slopes of the different sites.

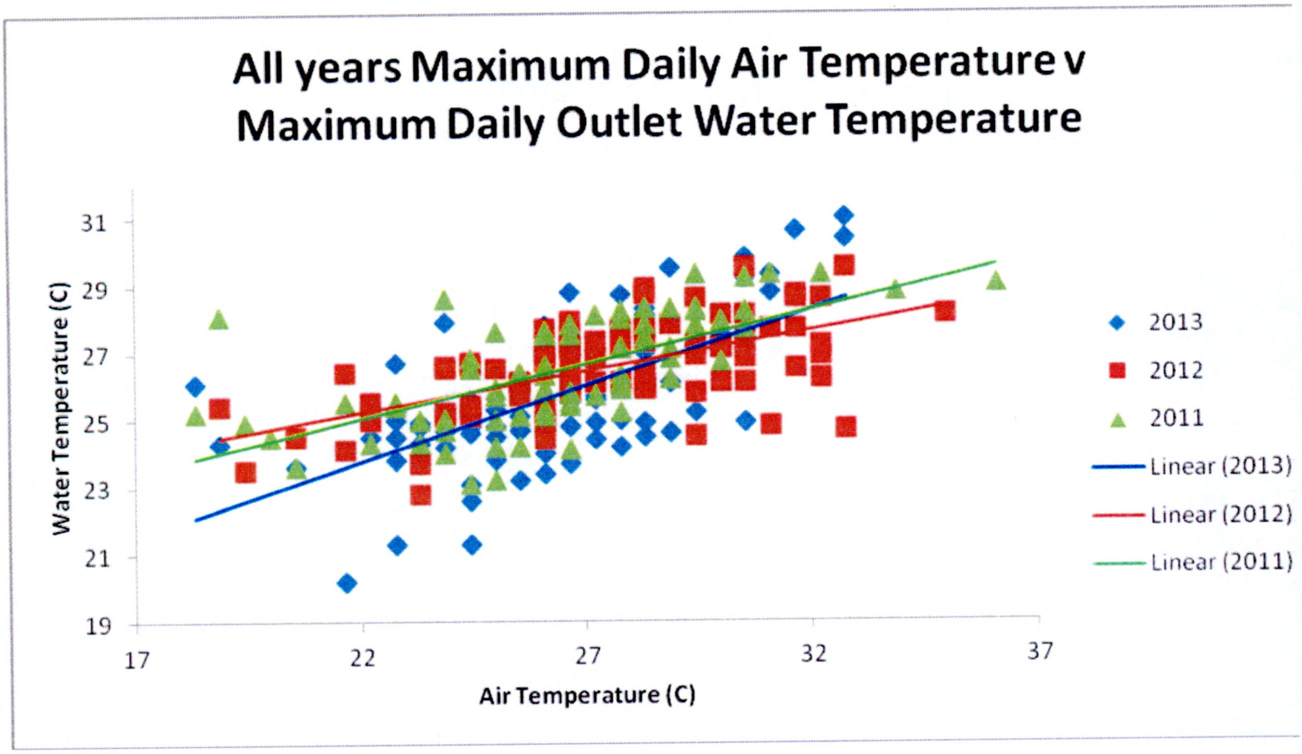


Figure 25. Daily maximum air temperature and daily maximum water temperature for the outlet site during all three summers. The summer of 2013 is in green, 2012 is in red and 2011 is in blue. There is a strong positive correlation between air temperature and water temperature.

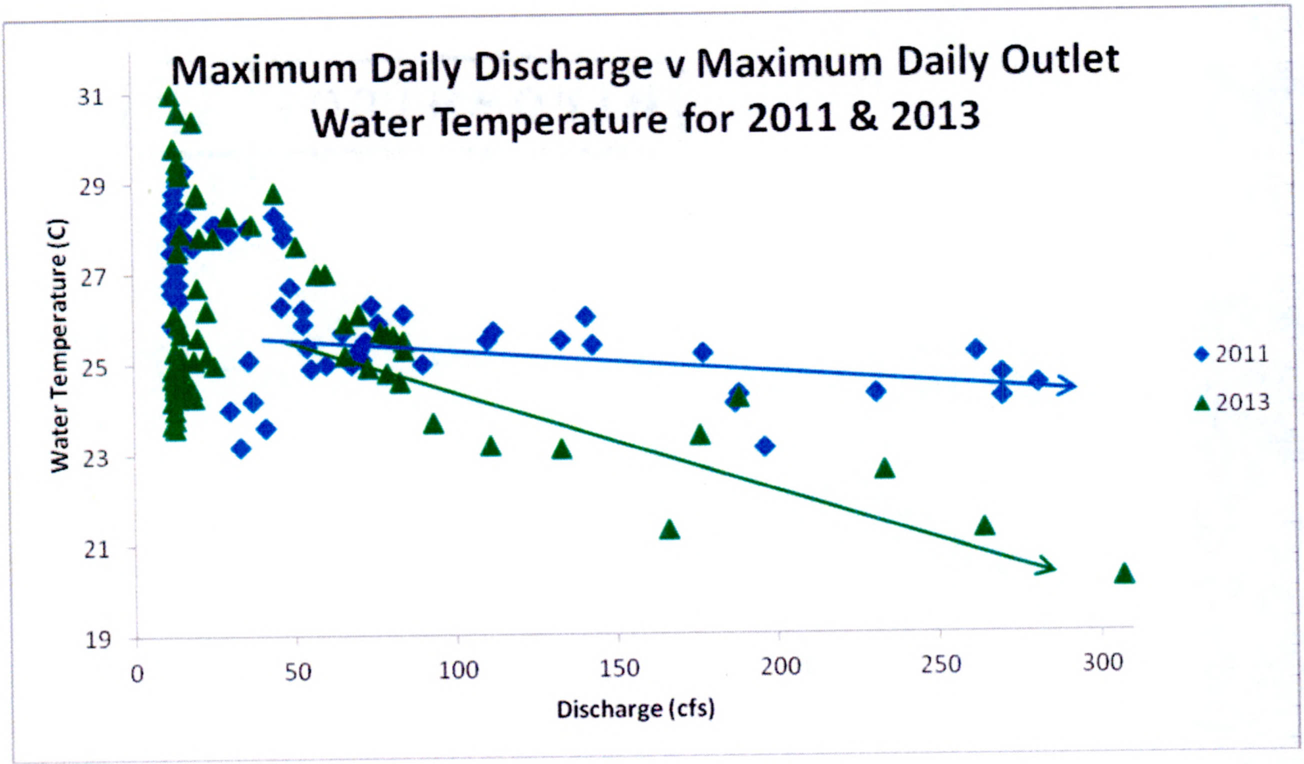


Figure 26. Daily maximum discharge and daily maximum water temperature for the outlet site during the summers of 2011 and 2013. A negative correlation can be seen in periods of higher discharge (>50 cfs).

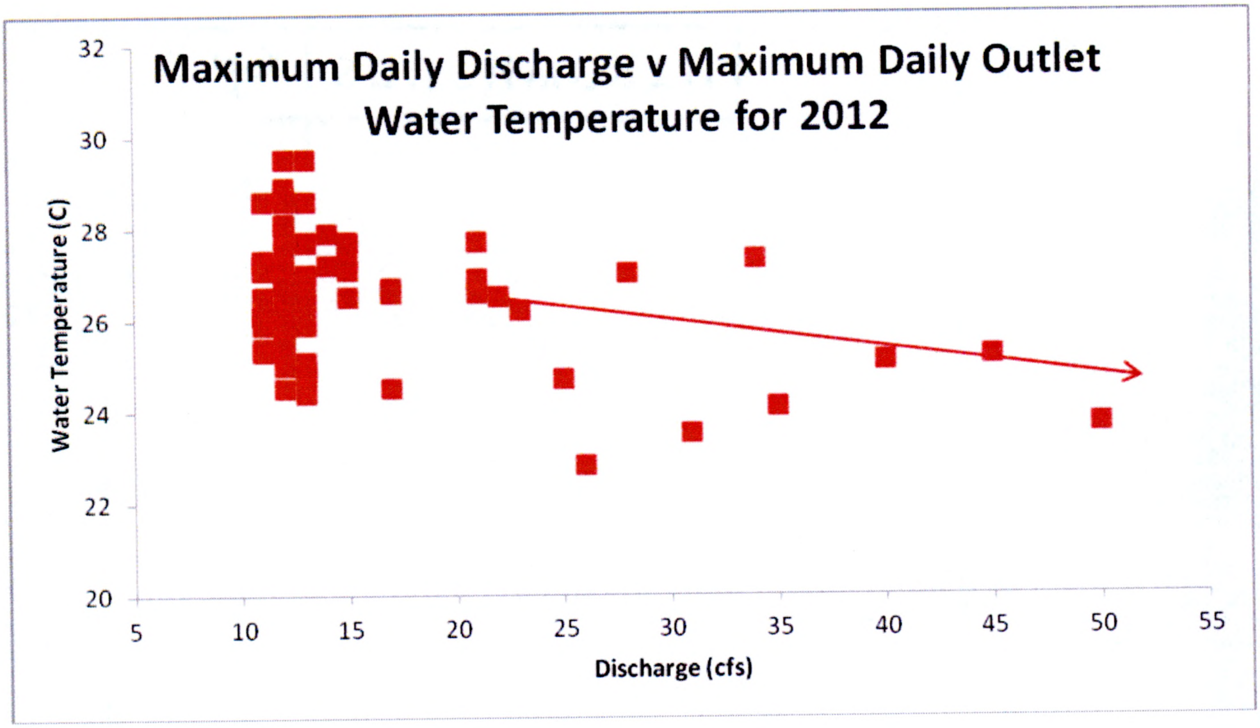


Figure 27. Daily maximum discharge and daily maximum water temperature for the outlet site during the summer of 2012. A negative correlation can be seen in periods of higher discharge (>20 cfs).

	2011	2012	2013
Outlet Site	59.9%	65.5%	35.3%
Willow St. Site	32.8%	32.1%	26.8%
Downstream Site	57.0%	0%	18.8%
Drain way Site		00.7%	
Tributary Site			0%

Table 1. The percentage of each summer in which the river temperature at certain sites was above 25 degrees Celsius.